ISSN 1548-7709 (Print)
ISSN 1930-1553 (Online)

Journal of Communication and Computer

Volume 10, Number 11, November 2013

David Publishing Company
www.davidpublishing.com

From Knowledge to Wisdom

Journal of Communication and Computer

Volume 10, Number 11, November 2013 (Serial Number 108)

David Publishing Company
www.davidpublishing.com

Publication Information:
Journal of Communication and Computer is published monthly in hard copy (ISSN 1548-7709) and online (ISSN 1930-1553) by David Publishing Company located at 240 Nagle Avenue #15C, New York, NY 10034, USA.

Aims and Scope:
Journal of Communication and Computer, a monthly professional academic journal, covers all sorts of researches on Theoretical Computer Science, Network and Information Technology, Communication and Information Processing, Electronic Engineering as well as other issues.

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Subscription Information:
Price (per year):
Print $520; Online $360; Print and Online $680

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Journal of
Communication and Computer

Volume 10, Number 11, November 2013 (Serial Number 108)

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Journal of Communication and Computer 10 (2013) 1365-1373

Making Software Engineering Education Structured, Relevant and Engaging through Gaming and Simulation

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Received: October 19, 2013 / Accepted: November 06, 2013 / Published: November 30, 2013.

Abstract: We as educators of software engineering practitioners are constantly seeking ways to design better learning experiences. We are not satisfied that a student can complete a software engineering project, but be able to work effectively in different kinds of projects, to be able to think and evaluate his actions. As such a domain model of software engineering that can be adapted to different engineering contexts is critical. We advocate Essence as a domain model. Essence is a software engineering language and kernel that originated from the SEMAT initiative, which attempts to increase the collaboration between industry, research and education. Through Essence we can design learning experiences that are relevant, structured, relevant and engaging. Structured–Essence provides an object-oriented state-based method-independent domain model of any software engineering endeavor. Relevant–Development teams can easily describe their way of working by using the building blocks provided by Essence and training materials described using Essence can be adapted easily to any specific development team. Engaging–Essence use of cards and game boards makes learning more engaging as students move cards around, or play with them like a poker game. This paper gives an overview of Essence and a catalog of development and process improvement games based on Essence. We assemble to these games into a process improvement workshop for an embedded product company and describe our experiences and results running this workshop.

Key words: Software engineering, education, gamification, simulation, learning, card games, board games, Essence, SEMAT, kernel.

1. Introduction

Software engineering is a rapidly evolving field. As businesses evolve, so software engineering methods evolve too. At the same time, software engineering is a rapidly growing field with many graduates joining the workforce each year. This gives rise to huge educational challenges. How do we teach software engineers, current and prospective ones? How do we make sure they remember what we teach? How can we make learning fun? How can we help them build on what they know to solve more complex problems? How can they learn new methods quickly?

Learning software engineering is quite unlike learning software programming (including software technologies like mobile development—Android, IOS, etc.). Students learning to program can write programs, compile and run them and view execution results as feedback. After trying a representative set of programming exercises, the student becomes proficient. Students learning software engineering are often put through some kind of class project. But working on a class project does not give software engineering students the same kind of rapid feedback as learning to program. In addition, the project cycle is much longer than a programming cycle. As such, students of software engineering are usually exposed to one mode of software engineering in school (undergraduate or post graduate). The danger is that these students are led to think that there is only one way to software engineering when there are in fact many ways to do so. The challenge is then how to expose students to the large number of situations that occur and equip them to

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respond better. Teaching students software engineering is not about teaching them to do software engineering, but more about how to think about software engineering—being able to compare different actions and their consequences in different contexts.

This is where having a domain model of software engineering like Essence is beneficial. Essence stems from the recent SEMAT initiative by Ivar Jacobson, Bertrand Meyer and Richard Soley that attempts to mature the state of software engineering and bring together industry, research and education [1], [2]. Essence is an extensible software engineering language and kernel that identifies the common ground across all software engineering endeavors [3]. Essence has been demonstrated in small and large development projects[4].

In this paper, we will describe how Essence makes learning relevant, structured and engaging.

(1) Structured-Essence provides an object-oriented state-based method-independent domain model of any software engineering endeavor;

(2) Relevant-Development teams can easily describe their way of working by using the building blocks provided by Essence and training materials described using Essence can be adapted easily to any specific development team;

(3) Engaging-Essence use of cards and game boards makes learning more engaging as students move cards around, or play with them like a poker game.

In particular, we show how Essence's object-oriented and state-based approach facilitates learning through a human-in-the-loop gaming and simulation. We support our arguments with results and experiences from an industrial case study. This paper is organized as follows. Section 0 provides a brief survey of learning and gaming in software engineering. Section 0 provides quick introduction of Essence and how cards make Essence tangible to practitioners. These cards are useful not only for actual project work, but also for learning and gaming. Section 0 catalogs various games teams and learners can play using Essence and the cards. Section 0 describes a case study involving an embedded product company using Essence for learning and gaming. Finally, Section 0 concludes and discusses our ongoing and future work in applying Essence.

2. Learning through Gaming—A Brief Survey

Gaming makes learning constructive, fun and engaging. There is also a growing interest in serious games [5] that introduces gaming concepts into normal work. With careful design, games can apply constructivist approaches [6] to help learners construct their own knowledge to make learning an even more rewarding experience.

The use of games is littered throughout the history of software engineering. Many of these games involve the use of cards, game boards and even computers. CRC (Class Responsibility Collaboration) cards are used to teach engineers how to identify and scope objects [7]. Agile development makes use of planning poker cards for collaborative work estimation [8]. Agile development's use of task boards and kanbans [9] are also examples of game boards. By making the current state visible, participants are engaged in thinking about what to do next. These techniques which we just described are used not only during training, but also in actual work removing the gap between learning and doing.

Smith and Gotel [10] invented RE-O-POLY, a board game similar to Monopoly. RE-O-POLY helps students think about how to solve different requirements engineering scenarios challenges. Baker and Navarro [11] also experimented with card games for teach software engineering. Navarro and Van der Hoek [12] developed SimSE a single-player computer game to teach software engineering. Jain and Boehm[13] developed SimVBSE, a computer game for teaching value based software engineering. Unlike games in the previous paragraph, these games here are purely training games used only in a classroom setting.

However, not being subject to actual project timing and resource constraints, students can play such games multiple times with different scenarios in compressed time. This helps broaden students' knowledge and experiences quickly.

Some educators make use of writing games to teach programming [14]. This gets students' interest because they can show what they built with their friends. In particular, Scratch [15] provides a simple game development environment to encourage teenagers to learn programming.

It is without doubt that games are important for learning, and games can take different shapes and forms, ranging from card games, board games to computer simulation games, and so on [16]. Shubik[17] highlighted in 1989 that every decent business school has its own homegrown game in its curriculum. Perhaps, we should endeavor to make this statement true for software engineering schools. In this paper, our focus is on teaching software engineering, as opposed to programming. But first we need to provide a simple domain model of software engineering, which is where Essence becomes very useful and powerful.

3. Essence and the Cards

Essence is a language and kernel of software engineering useful for describing and enacting software engineering methods. For brevity, we will not go into detail of every element in the Essence language, but concentrate on the ones that are related to the scope of his paper, specifically alphas. An alpha represents a dimension of software development risk and complexity. The Essence kernel identifies 7 such method-independent alphas prevalent in all software development endeavors, namely: Opportunity, Stakeholders, Requirements, Software System, Team, and Work and Way of Working. Each alpha has a series of state progressions to help development teams understand and deal with the risks and challenges for that alpha. For example, the progress of (a set of) Requirements go through the following states: Conceived, Bounded, Coherent, Acceptable, Addressed and Fulfilled. The Essence kernel provides detailed checklist of what each alpha and what each state means.

Essence presents the alphas and their states in a lightweight manner using poker size cards. Fig. 1 shows the Requirements alpha card on the left, and Requirement alpha state cards on the right for the Coherent and Acceptable states. The number at the bottom of each state card denotes its sequence. For example, Coherent is the 3rd out of 6 Requirement alpha states, State cards not only help team members understand the definition of states and their checklists, but also useful for running software development and gaming.

Using Essence for software development follows a simple Plan-Do-Check-Adapt cycle [4]. Planning is about determining the current state of development based on alpha states and the target state for the next iteration or time frame. Doing is about performing tasks to achieve the target states. Checking is about

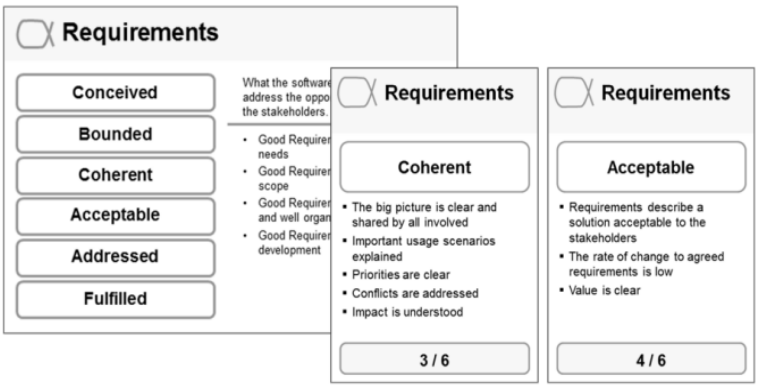

Fig. 1 Requirement Alpha and State Cards (Coherent and Acceptable).

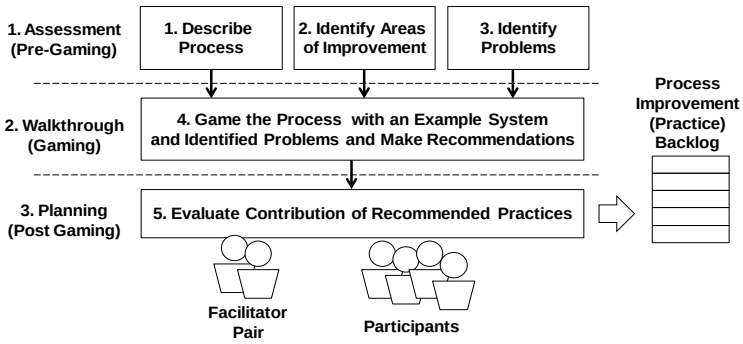

Fig. 2 Workshop outline.

determining whether the states are reached, which can be conducted daily or at the end of each iteration. Adapting is about changing how a team achieves each target state.

Though Essence is still at its infancy, work on Essence is rapidly growing, such as applying Essence in small and large development [4] as a framework for software engineering education [18], and as a framework for systematically reporting empirical findings [19]. This paper adds to this body of knowledge in the area of learning and gaming.

4. Learning and Gaming with Essence

In this section, we describe how we use Essence in learning and gaming. Klabbers [16] provided taxonomy for classifying games and described games in terms of actors (i.e., players), resources (pieces to move, cards, game boards, etc.) and (game) rules. In software engineering, actors would naturally be team members. Essence's cards, alpha states and such provide excellent gaming resources. Game rules will depend on the learning objectives. We categorize two broad classes of games that can be played using namely development games and process improvement games. These games are in nature collaborative as opposed to competitive because software engineering is fundamentally collaborative and principles for collaborative game design [20] should apply to these games.

4.1 Development Games

Development games are collaborative games whereby team members (actors) achieve some desired development goals.

Development State Game—The game helps participants reach a common understanding of the current state of a development endeavor (which can be an actual project or an exercise) expressed in terms of alpha states [4]. Each member has a deck of alpha state cards. At each turn, each member selects one state card for each alpha that best represent the current state of development and puts the cards face down. When every team member has done so, all turn over the cards. They discuss the possible differences, which usually can serve to highlight project risks or different understanding of what the alpha state means. This repeats until they all select the same cards.

Work Scope Design Game—This game helps participants agree on the scope of a particular team (e.g., a development team, a testing team, a customer facing team and so on). The participants draw boxes on a large piece of paper, each representing the scope of a team. A participant distributes alpha state cards according to what he/she thinks to be the responsibility of each team and explains it. The next participant with a different opinion will shift an alpha state card from one box (team) to another and give explanations. This repeats until all participants agree on the responsibility assignments. Since each alpha will have its states distributed across different teams, it provides a way to discuss how teams collaborate, or handover information between each other.

Project Milestone Planning Game—This game helps participants understand the criteria for achieving each

milestone in a software development lifecycle (SDLC). This is useful especially for small and medium companies who often do not have a clear definition. This game is similar to that above, but instead of distributing alpha state cards to teams, they distribute alpha state cards to milestones. The value is helping participants think holistically what needs to be achieved for each milestone across various dimensions (as defined by Essence alphas).

Task Planning Game—This game is a continuation of the current development state game for participants to plan how to achieve next alpha states. Having agreed on the current alpha states, the participants select the target alpha states to be achieved for instance the next iteration. A participant picks one of the alpha state cards and identifies tasks needed to meet the alpha state criteria and explain to other participants. If the next participant disagrees, he/she can add/remove tasks and give explanations. If the participant agrees, he selects another alpha state card to identify tasks needed. This repeats until there is an agreed set of tasks (also known as a task backlog) to achieve the target alpha states.

Development Game—This is a continuation of the task planning game and requires a facilitator to inject problems and issues that a typical team might face. From the task planning game, participants have an agreed set of tasks from which they would take turns to estimate and explain the effort required (in terms of man-days. Once all tasks are estimated, the development-gaming cycle starts. A participant selects a task to perform and throws a dice. If it is not a 6, the participant deducts the remaining effort from the task. If a 6 is thrown, the facilitator raises a problem or issue such as a requirements change, a severe bug and so on. The participant than explains how he/she would address the problem, which may require adding new tasks. This repeats for each participant until all tasks are completed or until the participants have explored sufficient problems and issues. The value of this game is that it helps the team seeks solutions to problem in a development context.

4.2 Process Improvement Game

Process improvement games are those that help team members evaluate their current way of development, identify problems and agree on ways to improve them.

Process Assessment Game—This game helps participant pinpoint where problems occur in their development expressed in alpha states. Participants first write down the problems they face in post-it separate notes. A participant explains a problem and indicates where the problem occurs and when it is normally resolved in terms of alpha states. If another participant has a similar problem, this problem has its score count increased by one. This repeats until all identified problems are associated with some alpha states. From this game, participants have a very clear picture of where problems occur, the critically (in terms of the scores), and which alpha states they should improve. The problems identified can be used by facilitators in the development game described above to make the latter more relevant to participants.

Practice Definition Game—This game helps participants to understand how practices help address their problems. In Essence terminology, practices are repeatable ways of solving some software engineering problems. Practices can be well known ones such as acceptance test driven development (ATDD), iterative development, a particular requirement-engineering technique, etc. . A facilitator first explains how a candidate practice works, probably including some exercises (e.g., how to write acceptance test cases). A participant then picks an alpha state and explains what needs to be done at that state. For example, the requirements coherent state requires writing acceptance test cases, and the Requirements Addressed state requires key test cases to be successfully executed. The next participant selects another alpha state and explains what the practice requires for that alpha state. This repeats until the practice is fully defined (or mapped) to the relevant alpha states. Note that this game can be played with home grown practices which participants improvise. The results of this game are

also useful for the task planning game described earlier as it helps participants identify tasks needed to fulfill each alpha state.

Practice Selection Game—This game helps participants select practices that can address their problems. It is a continuation of the above two games. The process assessment game produces an alpha state mapping to problems participants face. The practice definition game produces a practice to alpha state mapping describing the additional work and checks needed at associated states. Before playing this game, participants must have several alpha state mappings for several practices. A participant first chooses a candidate practice. The next participant explains how the practice helps solve a problem at his/her chosen alpha state. The next participant continues with the next alpha state and so on, perhaps selecting another practice. This continues until the identified problems are sufficiently addressed.

5. Process Improvement Case Study

This section describes the experiences of running a process improvement and gaming workshop for an embedded product development company with 500 developers. This company wanted to evaluate how agile practices can help solve their development problems. They had not previously heard of Essence before and we took this opportunity to run the above mentioned games as we believe it would help them understand agile practices better, and how these practices would fit their development context.

38 participants joined our workshop comprising a broad range of roles, from department heads to testers. We broke them up into four groups. Each group had an even distribution of roles. The first author was the primary facilitator of the workshop pairing with a facilitator from the product development company for two important reasons: (1) to provide company specific inputs and support; (2) to become the company's internal coach when introducing the practices after the workshop. Fig. 2 outlines the workshop, which comprise two intertwining threads: a process improvement thread (assessment, walkthrough, planning) and a (human) gaming thread (pre-gaming, gaming, post-gaming).

The process improvement thread begins by assessing the participants' current process and problems. From the gaming perspective, this step provides the inputs to tailor the simulation game to the participant's specific context. The next step in the process improvement thread walks through the participants' process to explore ways to improve and recommends practices the participants ought to use. This walkthrough is in effect running the (human) simulation game. Gaming involves walking through the alpha states from first state to the last state for all relevant alphas. The final step reviews recommended practices based on how they contribute towards improving the participants' process, and put these practices into a process improvement backlog that serve as the participants' next steps after the workshop.

5.1 Assessment—Pre-gaming

We conducted the assessment (pre-gaming) step by (1) playing the project-milestone planning game to understand their process, (2) agreeing on alphas that takes improvement priority, and (3) playing the process assessment game to pinpoint where their problems occur.

The participants' software development lifecycle has the following milestones: KO (kick-off), ES

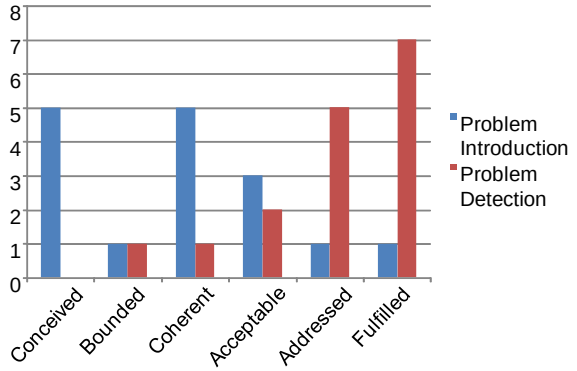

Fig. 3 Occurrences of problem introduction and detection by requirements Alpha States.

(engineering sample), Alpha, Beta, RC (release candidate) and RTM (release to manufacturing) phases. The project-milestone planning game resulted in an alpha states mapping for their SDLC as shown in Table 1.

The numbers in Table 1 represents the state number for the respective alpha in each row. For example, Requirements must reach state 3 and 4 (i.e., coherent and acceptable) at the Engineering Sample (ES) milestone. In the actual workshop, participants were shifting the alpha state cards instead. The value of this simple exercise was twofold: It helps external facilitators to understand their existing process, and for development teams to get acquainted with Essence alpha states and understand the universality of Essence.

We asked the participants to vote for areas that needed most improvement. The participants' believed that Requirements and Stakeholders had the highest need for improvement followed by Way of Working, Team, Opportunity, Software System and Work.

The participant played the process assessment game and tabulated the results. For example, a participant had a problem of "having different understanding of requirements between customers and the team". This usually occurred at Requirements state Conceived, and was usually detected at Requirements state Bounded when attempting to agree on Requirements scope. We then tabulated the types of problems raised and plotted the number of occurrence of problem introduction and usual problem detection by Requirement states in Fig.3.

From Fig. 3, it is clear that it would be beneficial for the participants to be equipped with the ability to detect problems earlier, especially when they were at the Requirements Coherent state. This phenomenon hints that a practice like ATDD (acceptance test driven development) would be very useful. By walking through the identified problems, the facilitator could determine practices that might be of useful to the participants. These practices would be introduced to the participants during walkthrough/gaming. From the gaming perspective, the problem types become impediments that we can introduce to the development simulation game.

5.2 Walkthrough——Gaming

The second phase of the workshop involving process walkthrough and gaming is the most complicated part of the workshop. It requires experienced facilitators who understand how to interact with the participants and address their specific problems through relevant practices. Table 2 summarizes the simulation gaming steps, which involves a series of games described earlier.

5.3 Improvement Planning (Post Gaming)

From the simulation gaming, both participants and facilitators had good hands-on experience with identified problems and recommended practices. We used the Practice Selection Game to wrap the process improvement workshop. This game gave participants a chance to discuss their experiences with the recommended practices, their usefulness in addressing their problems, and possible issues when applying them in real projects.

Table 1 Describing Existing SDLC Using Essence.

Alpha	Phase					
	KO	ES	Alpha	Beta	RC	RTM
Opportunity	1, 2, 3	4				5
Stakeholders	1, 2	3, 4				5
Requirements	1	2, 3	4, 5	6		
Software system	1	2		3	4	
Work	1, 2	3, 4				5, 6
Team	1, 2	3, 4				5
Way of working		1, 2, 3	4, 5			6

Table 2 Simulation gaming steps.

Prepare List of Requirement-Items in a Backlog
Plan-Do-Check-Adapt gaming cycle
Agree cycle objectives based on:
Target alpha states
Requirement-items to deliver
Determine tasks to achieve cycle objectives (Task Planning Game)
Simulate cycle (Development Game)
Review current state (Current State Game)

5.4 Workshop Evaluation

Through gaming, participants were highly engaged, something which they had never experienced in a workshop before. We asked the participants what they liked about the workshop and what could be improved, whose results are listed below:

What participants liked—Participants liked the interactive, collaborative and gaming nature of the workshop, and in particular gaming through their process. In fact, the participants had lots of fun throwing dice, which help them get engaged. This helped them appreciate agile development concepts. They also appreciated the use of Essence alpha states that provided a systematic approach to think about progress and to describe their SDLC (software development lifecycle).

What could be improved——They preferred using an example closer to their domain. As mentioned, they were building embedded systems whereas the simulation gaming was about building a web application. They suggested that we spend time to customize such an example before the workshop.

6. Conclusions and Future Work

Software engineering is complex and difficult to learn and master. As a conclusion, we re-visit our goal to make learning experiences structured, relevant and engaging.

Structured—Essence provides a simple object-oriented state-based domain model of software engineering endeavors. This domain model provides a mental model for students to understand and think about software engineering.

Relevant—There is a mapping from the abstract domain model described in Essence onto students' specific engineering context. Exposing students to this mapping is a very important skill. This is because there is no one-size-fits-all in software engineering. Every software engineering is different. In our simulation, we expose students to perform this mapping (e.g., mapping lifecycle to alpha states)

Engaging—In this paper, we demonstrated how to use Essence to help practitioners learn software engineering through games and simulations. We provided some gaming mechanics, a catalogue of games and demonstrated how we assemble these games into a process improvement workshop. The results and experiences are promising, as participants in the workshop had never been so engaged when they learn software engineering before. We believe that as we work more with Essence, we can discover more games and improve the rules and facilitation of existing games.

A natural follow up to this work is to provide more guidelines so that less experienced coaches can act as facilitators. We would also like to try out different variations as to how we can conduct the workshop better. Computer-based gamification is an area that is receiving increasing interest [21], and naturally, we would explore this area further.

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Journal of Communication and Computer 11 (2013) 1374-1380

Conditional Statement Dependent Communications

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Received: October 11, 2013 / Accepted: November 10, 2013 / Published: November 30, 2013.

Abstract: We confirm relevance to a before proposed norm and deontic logic associated, archetypal taxonomy (TXY) for "control and communication of information certainty and security" (COINS). The confirming evaluation is based on results from a, to the COINS independent, case study concerning networking among BHE (biomass heating enterprises). For the TXY's relevance, we extend the proposed model. Then the presented BHS results, of mutual, with principal–P/agent–A associated, provider–P/customer–Q independence/dependence, are found being isomorphic with the conditional statement approach having (true–T)/(false–F) alternatives for what level of the P/Q independence/dependence causes level of activity. The COINS' model and the BHE results are merged according to the scheme; TXY; PQ: BHS (independence $\in x$|activity $\in$ y): (1) Opportunity; PQ = FT: (0.7|0.85), (2) Strength; PQ = TT: (0.55|0.55), (3) Weakness; PQ = FF: (0.9|0.65), and (4) Threat; PQ = TF: (0.55|0.85). For the sake of effectiveness, the TXY–model and the accompanied reasoning clarifies that communication opportunity and strength depend on negligible infrastructural risks; i.e., the impact of environmental technology and corporeal related weaknesses and threats have to be kept controllable for any meaningful messaging session.

Key words: Strength, weakness, opportunity, threat, risk.

1. Introduction

The TXY $\in$ COINS [1] and the BHE [2] report, as most of the references, are accessible online.

In the current paper, the vocabulary relies on the open English dictionary [3], information technology standards [4] and symbols [5].

A legend: The keywords; SWOT–RSK, concern any contextual–CXT $\supseteq$ {6WH | what, when, where, who, how, why} HOL (holistic) aspect on a SYI's (system–of–interest) and its ESY's (enabling–systems) BEH (behavior) for MSG (messaging) and IPR (interpretation) of MNG (meaning) as INF (information) with AUT (authenticity), COF (confidentiality), ITY (integrity), RBY (reliability), ACT (accountability) and NRP (non-repudiation) for KNW (knowledge) to be COG (cognized) for TXY (taxonomic) CTR (controls) of Act (action) PEFs' (performance) based on FEBs (feedback) of EALs (evaluation) and VUE (value) ECTs (effects).

Fig. 1 is an orienting introduction to the current extension of the reasoning in Ref. [1] for the proposed TXY.

The rest of the article is organized as below:

Section 2: The conditional statement definition; e.g., the propositional calculus '$p \rightarrow q$' $\equiv (\neg p \vee q)$ and implementation of rules of inference; i.e., "P contains Q" $\equiv (P \supseteq Q) \equiv$ "Q is contained in P" $\equiv (Q \subseteq P)$ [5, 6].

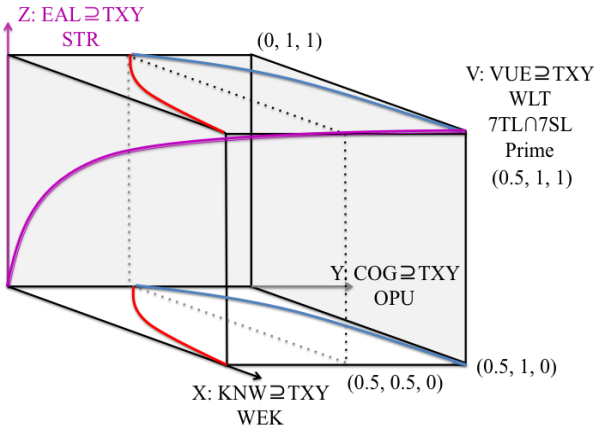

Fig. 1 Introduction to the TXY-model [1].

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Section 3: The communication model; goal decision with respect to the seven technology layered–7TL ubiquitous infrastructure for the seven society layers–7SL; i.e., (7SL ∩ 7TL) is an extension and precision of the proposed COINS' TXY [1].

Section 4: The adaptation is for communication: implementation of (7SL ∩ 7TL) causes evaluation of implication; i.e., MSG ⊇ MNG.

Section 5: Corporeality dependent–DPY adaptation; i.e., (7SL ∩ 7TL) is a TXY effectuation concern.

Section 6: Independent case association; the 6WH independent BHE (biomass heating enterprises) independence/activity study results [2] are found to support the generality of the TXY approach.

Section 7: Conclusions; generality in common EAL criteriaprinciples promotes interdisciplinary COM through reduction of, by FEB observed and COG, asymmetries in the parts networking independences/activities.

2. The Conditional Statement Definition

The conditional statement or implication–($p \rightarrow q$) proposition: "'If p then q' or, less often, 'q if p'" [5] true–T and false–F alternatives are in Table 1 for Fig. 2 usage. In Ref. [6], the '$p \rightarrow q$' is, among other propositions, denoted as f_{13} and defined as deduction. The logical equivalence '$p \rightarrow q$' ≡ ($\neg p \vee q$) ≡ [$\neg$($p \wedge \neg q$)]: $f_{13} \equiv (\neg f_2)$ [6].

The implications–IPL are generically multilayered seven social layers–7SL plus seven technological layers–7TLasis given in Ref. [1], of which is the COM ⊇ CXT of ISC (information security) ∈ COINS NRM (normative)–"deontic, of or relating to duty and obligation as ethical concepts [3]"–TXY (taxonomy) approach. The, "many–sorted implicative conceptual

Table 1 Conditional statement or implication truth table.

p	q	p → q	(p → q) ≡ (¬p ∨ q)	p ↔ q	Fig. 2
T	T	T	T	T	II
T	F	F	F	F	IV
F	T	T	T	F	I
F	F	T	T	T	III

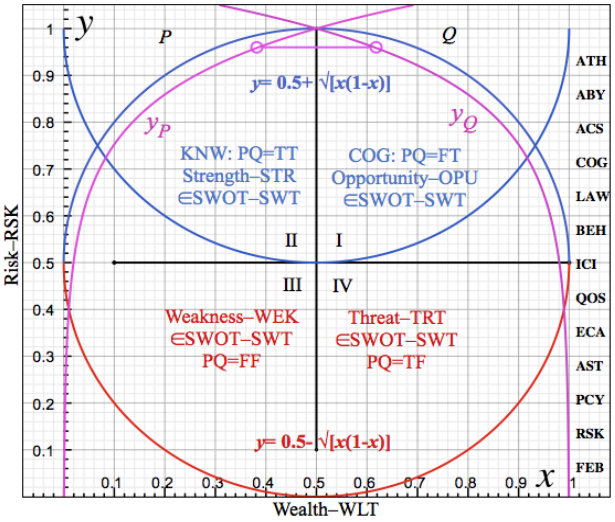

Fig. 2 The model is an extension [1] for inference rule [5].

systems"–msic [7] as metalanguage, for different fields and areas, has the notation $p \rightarrow B(q)$ (ibid, p. 5). In the normative CXT ∈ COINS [1], the 'B' stands for alternatives "can/behave strategy–STY" or 'shall/be have tactic–TAC' or 'is/has/has had operations–OPE for fields [7]:

- "The formal representation of laws and legal contracts;
- The specification of aspects of computer systems in the formal theory of organizations;
- The analysis of notions such as responsibility, authorization and delegation;
- Agent–oriented programming;
- Agent communication languages."

And areas [7]:

- "Formal representation of legal knowledge and normative multi–agent systems;
- Specification of systems for the management of bureaucratic processes in public and private administration;
- Specification of database integrity constraints computer security protocols;
- Analysis of deontic notions in the area of security and trust;
- Digital rights management and electronic contracts;
- Access control, security and privacy policies." [7]

The "requisite variety width"–RQW ∈ COINS [1] can be treated as associable with the *msic* ∈ deontic [7] aspects.

In the information certainty and security–ISC CXT (context) [1] is pointed out the risk–RSK of aristocracy[8] in BEH. Such kind of BEH does not respect the peer–to–peer equivalence–($p \leftrightarrow q$) conditions, in "provider–*P*' →"questioner–*Q*', for mind–to–mind communication–COM relations between different SYI or its ESY [4, 9]. These conditions are supposed being caused by not accurately adapted–APT or ATH (authorized), seven 7TL; i.e., DCT (data communication technology), driven corporeality [3].

For ATH of PWR (power)–in ROL (role) as Act (actor), the VUE assessment depends on; knowledge, skills (i.e., RQW (requisite variety width) COG (cognition)), responsibility, effort and working conditions [for COG of CXT ⊇ 6WH "shall be" done for what ∈ 6WH MNG] [7].

3. The Communication Model

Above Fig. 1 is an introduction to the below, from Ref. [1] adapted, Fig. 2. The center of the circle is in, (x, y) = (0.5, 0.5). The scenarios are supposed to be from *P*'s point of view of interest to be requisite RQW adapted–APT to *Q*'s needs and wants about QOS (quality of service); i.e., the indicator of *P*'s capability as VUE PEF (performer).

The EAL (evaluation) of QOS' VUE and PEF are context–CXT dependent F2F or B2B in enterprise–EPR2EPR or entity–ETY2ETY relations.

The MGT (management) of the lower sectors, 7TL ~ (III ∩ IV) ∈ Fig. 2 for MSG transparency, condition the existence of the upper VUE creating sectors, 7SL ~ (I ∩ II) ∈ Fig. 2 for MNG. With respect to mutual dependences for MNG, probability P ∈ COM:

$$P\left[(7SL)|(7TL)\right]=\frac{P(7SL\cap 7TL)}{P(7TL)} \tag{1}$$

The lower part ∈ Figs. 1 and 2 is DCT ⊃ 7TL MGT dependent. The Fig. 3, as archetypal representation of the conditions, is exemplified with the "Johari" [10] window areas and the prisoners' dilemma characteristics [3, 11]. The upper part ∈ Figs. 2 and 3 is 7SL MGT dependent. For ISC, the 7TL ∩ 7SL ↔ MSG ⊃ MNG transparency is through API (application) ⊂ 7TL to APT ⊂ 7SL requirements. This 7TL ∩ 7SL has to be EAL (evaluated) and MIT (maintained) for kept ACR (accredited) within the LCP (life cycle period) [9].

The APT ⊂ ACR begins with implementation of MNG ∈ keywords; {SWOT| STR (strength), WEK (weakness), OPU (opportunity)} ≡ SWT [12] for, on FEB based, decision and effectuation of a mandatory PCY (policy) ⊃ {FEB, RSK, MGT}.

The RSK (risk) function y_P ∈ Fig. 2 is expanded in Fig. 4. The y_P and its mirror part y_Q are, because of the COM goal definition [1] approach, for reducing of the corporeal impact RSK in MSG. The estimated uncertainty is:

$$\left|\varepsilon\right|_{UCY}=\left\{x+\sqrt{x(1-x)}\right\}\cdot y_P:\quad 0.021\le x\le 0.382,\ \text{else}\ \left|\varepsilon\right|_{UCY}=x\le 0.011 \tag{2}$$

Fig. 4 is transformed is transformed from Fig. 5.

Function y_P ∈ Fig. 4 is transformed from Fig. 5 of which represents the exponential density function [13]:

$$f(x)=\begin{cases}1/e^{-1/x}, & \text{if } 0\le x<\infty,\\ 0, & \text{otherwise.}\end{cases} \tag{3}$$

II: PQ = TT, STR ∈ SWT (a) Equivalent (Uncertainty): STR. Negotiations for certainty. (b) Johari 1: free area (c) altruistic, when each is symbiotic, benefitting chiefly from the efforts of others	I: PQ = FT, OPU ∈ SWT (a) Symbiotic (*Q* need of *P* QOS ability. *P* respects the *Q*'s 6WH will and needs. (b) Johari 3: hidden area (c) egoistic, when the player is competitive, working for his own satisfactions alone
III: PQ = FF, WEK ∈ SWT (a) Redundant (Unknown possibilities). Innovation and risk synergy openness. (b) Johari 4: unknown area. (c) egalitarian, when all are cooperative, sharing alike	IV: PQ = TF, TRT ∈ SWT (a) Parasitic (*P* dominates *Q*). *P* dominates the 6WH scene. (b) Johari 2: blind area. (c) despotic, when all players work chiefly for the benefit of single one, who is parasitic
(a) TXY [1, 4]; (b) Johari windows [10]; (c) Prisoners dilemma [3, 11]	

Fig. 3 A compound of Table 1, Figs. 1 and 2, johari windows and prisoners dilemma.

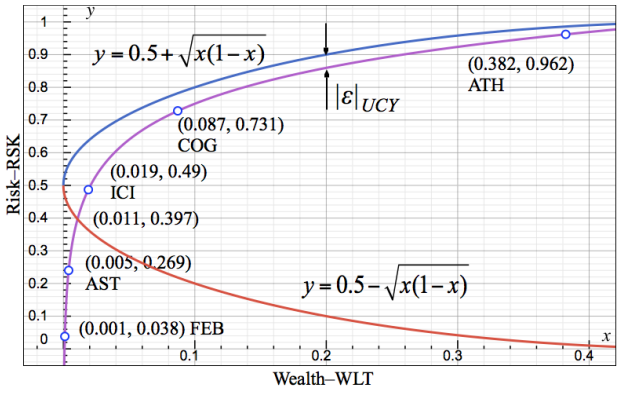

Fig. 4 Expansion of $x \in$ Figs. 1 and 2, $\Delta y = (1/13) = 0.0769$.

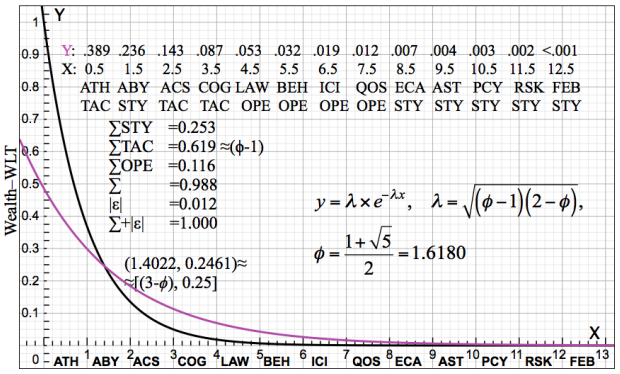

Fig. 5 Values $\in y \in x$ and values $\in x \in y$ (1 - x/13) in Figs. 1 and 2.

Function $y \in$ Fig. 5, where $\phi \in$ golden ratio [6], is calculated with $\lambda = 0.4859$ for $y_P \in$ Fig. 4:

$$x = 0.4859 \times e^{-13 \times 0.4859 \times (1-y)} \rightarrow$$

$$\rightarrow \ln\left|\frac{x}{0.4859}\right| = 13 \times 0.4859 \times (y-1) \leftrightarrow \quad (4)$$

$$\leftrightarrow y_p = \frac{\ln\left|\frac{x}{0.4859}\right|}{13 \times 0.4859} - 1 \leftrightarrow y_p = \frac{\ln|2.0580 \times x|}{6.3167} + 1$$

The $\lambda \in \phi$ area:

$$F(x) = \int_0^{13} / e^{-/x} = \left[e^{-/x} \right]_0^{13} = 1 - e^{-0.4859' 13} = 1 - |\varepsilon|; \quad (5)$$

$$|\varepsilon| = 0.0018$$

of which satisfies the Eq. (2) criterion $x \leq 0.011$.

Of basic importance is $[1\text{-}f(x)]$ for $x \in [0, 0.5] \leftrightarrow x \in$ [FEB, ICI] MGT.

4. The Adaptation is for Communication

If the Eq. (1) APT conditions are satisfied for RQW $\supseteq$ CXT, then VUE proposition exchange probability. In Figs. 2 and 4 we have to manage the $x = 0.5$ uncertainty; i.e., the intersection point of y_P and its mirror y_Q of which is to be avoided. Let x and $(1\text{-}x)$ represent independent probabilities [13]; i.e., p respective q are in different parts of a systems. Hence the conditional probability P:

$$x(1-x) \leftrightarrow pq \leftrightarrow p(1-q); \quad \mathrm{P}(p|q) = \mathrm{P}(p|q) \quad (6)$$

Now we have to arrange a physical; i.e., "layer 1" – L1 $\subset$ 7TL, transmission line between $x = 0.382 \in$ Figs. 3 and 4 and its mirror point $x = (1 - 0.382) = 0.618$ for the characteristic $z = r_0 \leftrightarrow |\lambda] = (0.382 \times 0.618)^{-0.5} = 0.4859$ (ohm, $\Omega \leftrightarrow$ volt/ampere, $V \times A^{-1}$ [14, 15]): The on data–DAT based messages–MSG, that cause the sort–less probabilities for CXT $\supseteq$ 6WH appropriate RQW, have to be transported as coded EGY (joule, J $\leftrightarrow$ V × A × s) quanta in bits between the ETY $\subset$ COM.

WLT (wealth) $\leftrightarrow$ EGY (J) is ACS (access) ⟨s⟩ to AST (assets) in parity with ATH ROL (PWR = V × A). RSK is loss of AST and is increasing with VUE~WLT.

The basic MNG $\subset$ COM transparency; i.e., the IMP (implementation) and IPL for RQW $\supseteq$ ($P \rightarrow Q$) shall be APT, PRT (protected) and MIT (maintained) $\subset$ DPY (dependability) for being kept ACR for SAF (safety) $\supseteq$ EPR within its LCP (lifecycle [9] period) $\cong$ f(WLT) $\leftrightarrow$ RSK.

5. Corporeality Dependent Adaptation

The basic $\in$ COM; i.e., Figs. 1, 2 and 4, $x \in [0, 0.5]$, is dependent on DAT and MSG. DCT $\supseteq$ 7TL $\in$ Fig. 6, and its APT, is basic for establishment and management–MGT of the high level RSKs. COG is 6WH "shall be" PEF for what $\in$ 6WH $\subseteq$ CXTMNG.

In CXT $\in$ Fig. 6, the goal is to propose how $\subset$ 6WH to APT $\subset$ 7SL to API $\subset$ 7TL; i.e., (7TL $\cap$ 7SL) for effect $\in$ PWR ⟨EGY × s^{-1}⟩, but with respect to corporeal [17] limitation $\in$ RQW of not explainable affections' like "ohs":

"Don't call sigs, half-uttered "oh's" dead words, you word–hacks! They count for more than all your sad songs and condolences. In "oh's" the spirit releases the

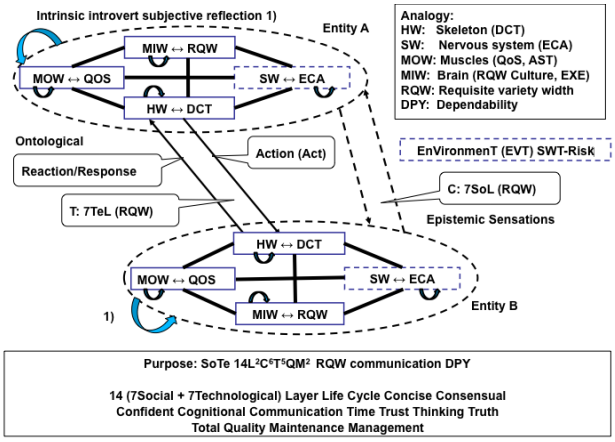

Fig. 6 The EPR (enterprises) as ETY's (entities') 7SL have to be APT to the 7TL and the EVT (environments) [16].

muted body and rushes forward to speak for it, but the Spirit alone speaks. There are unspeakable "oh's'!"[17]

But, the ambition is to discuss rational effects of how ⊂ 6WH for treating APT ≡ (7TL ∩ 7SL) in general; i.e., through (API ⊂ 7TL) ∩ ({APT, ECA} ⊂ 7SL) ∈ Fig. 6.

6. Independent Case Associations

The results from the independent case study concerning networking among BHE (biomass heating enterprises) [2] are given in Fig. 7 with motivations:

Group 1, (C). Mutual Dependence = Inter–dependence, PQ = TT: the (Fig. 4 ∈ [2] A and B) organizations (ETYs) have a tight relationship, in which they are mutually dependent on each other, having an equal amount of impact on their counterpart.

Group 3, (B). Unbalanced Independence PQ = FT: a loose relationship, where Firm A [↔*Q*] has more power than Firm B [↔*P*], i.e., Firm A [*Q*] is more independent. Firm A's power gives it more freedom to act, while firm B [*P*] can be influenced by the powerful Firm A [*Q*].

Group 4, (A).Mutual Independence=low dependence, PQ=FF: both (*P* and *Q*) organizations have full freedom to act according to their own objectives. Neither organization has significant influence over the other (but according to Fig. 8 the (independence | activity) ≈ (0.9|0.65)).

Group 2, (D). Unbalanced dependence, PQ = TF: asymmetrical dependence, where one party [*P*] will be able to dominate the other [*Q*]. The organization with the lower level of dependence [*P*] will have more freedom to maneuver and impose its conditions than its counterpart [*Q*] [2].

Fig. 7 results are adapted and included in Fig. 8 as extension of Fig. 3.

Group 3 (G3) is classified, as I ∈ Fig. 2 is the preferred alternative because, $p \rightarrow q \equiv (\neg p \vee q)$ == (F ∨ T) ∈ Table 1 has the interpreted meaning: $P \supset Q \equiv$

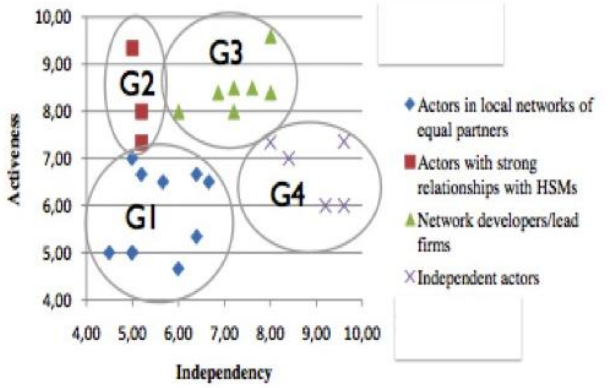

Fig. 7 The EPR as ETY's 7SL have to be APT to the 7TL and the EVT [2].

II: PQ = TT, STR ∈ SWT (a) Equivalent (Uncertainty): Negotiations for certainty. (b) Johari 1: free area (c) altruistic, when each is symbiotic, benefitting chiefly from the efforts of others. (d) Group 1, (C). Mutual Dependence = Interdependence: PQ = TT– (0.55|0.55)	I: PQ = FT, OPU ∈ SWT (a) Symbiotic (*Q* need of *P* QOS ability. *P* respects the *Q*'s 6WH will and needs. (b) Johari 3: hidden area (c) egoistic, when the player is competitive, working for his own satisfactions alone. (d) Group 3, (B). Unbalanced Independence: PQ = FT – (0.75|0.85)
III: PQ = FF, WEK ∈ SWT (a) Redundant (Unknown possibilities). Innovation and risk synergy openness. (b) Johari 4: unknown area. (c) *egalitarian*, when all are *cooperative*, sharing alike. (d) Group 4, (A). Mutual Independence = low dependence: PQ = FF – (0.9|0.65)	IV: PQ = TF, TRT ∈ SWT (a) Parasitic (*P* dominates *Q*). *P* dominates the 6WH scene. (b) Johari 2: blind area. (c) despotic, when all players work chiefly for the benefit of single one, who is parasitic. (d) Group 2, (D). Unbalanced dependence: PQ = TF – (0.55|0.85)
(a) TXY [1, 4]; (b) Johari windows [10]; (c) Prisoners dilemma [3, 11]; (d) BHE-study [2]	

Fig. 8 A compound of Table 1, Figs. 2, 3 and 7.

Table 2 [Independence (*i*)|Activity (*i*)] DIV [(*j*)|*j*]; e.g., OPU DIV STR = (0.75|0.85) DIV (0.55|0.55)=(1.36|1.55).

i|j	I: OPU 0.75|0.85	II: STR 0.55|0.55	III: WEK 0.9|0.65	IV: TRT 0.55|0.85
I: O	1.0|1.0	1.36|1.55	0.83|1.31	1.36|1.0
II: S	0.73|0.65	1.0|1.0	0.61|0.84	1.0|0.65
III: W	1.2|0.76	1.63|1.18	1.0|1.0	1.64|0.76
IV: T	0.73|1.0	1.0|1.55	0.61|1.31	1.0|1.0

"*P* contains the *Q*'s interests" and hence avoiding aristocracy in *P*'s BEH. In Fig. 8 (HSM (heating systems manufactures) are in Provider role–*P*), the $x \approx 0.75 \in$ independency causes $y \approx 0.85 \in$ activity.

The results are according to the scheme; TXY PQ – BHS (independence $\in x$ / activity $\in y$):

(G3) $\in$ I opportunity; PQ = FT with independence/activity $\approx$ (0.75|0.85); i.e., *Q* controls the scene.

(G1) $\in$ II strength; PQ = TT with independence/activity $\approx$ (0.55|0.55); i.e., balance between *P* and *Q*.

(G4) $\in$ III weakness; PQ = FF with independence/activity $\approx$ (0.9|0.65); i.e., *P* has the initiative.

(G2) $\in$ IV threat; PQ = TF with independence/activity $\approx$ (0.55|0.85); i.e., *P*'s activities may dominate the scene.

The conclusion, from *Q*'s and the TXY's point of view, is that; (1) high independence and high activity is opportunity, (2) equal independences and activities is strength, (3) high independence and low activity is weakness, and (4) low independence and high activity is threatening.

7. Conclusions

The Fig. 8 independence|activity values are compounded and related to each other in Table 2.

G3 $\equiv$ OPU/G1 $\equiv$ STR (independence | activity) = (0.75|0.85)/(0.55|0.5) = (1.36|1.55) of which is interpreted as the *Q*'s freedom relatively *P*; i.e., *P*'s avoidance of exceeding the prime state.

In Ref. [1] we have the corporate lifecycle–CRP [8] as reference for motivating the above Fig. 2, and in Fig.4 expanded, communication model. The stages $\in$ CRP motivates the stages$\in$Fig. 4 for TXY guided RSK MGT $\in$ Fig. 5:

Courtship/Affair $\approx$ Feedback–FEB $\in$Fig. 5: (WEK/TRT) = (1.64|0.76).

Infancy/Infant mortality $\approx$ Asset–AST$\in$Fig. 5:(WEK/TRT) = (1.64|0.76).

Go-Go/Founder or family trap $\approx$ Incident–ICI $\in$ Fig. 5: (STR/OPU) = (0.73|0.65).

Adolescence/Divorce $\approx$ COG $\in$Fig. 5: (STR/OPU) = (0.73|0.65).

Prime $\approx$ ATH $\in$ Fig. 5: (STR|OPU) = (0.73|0.65).

The indicated (WEK/TRT) asymmetry (1.64|0.76) has to be reduced with adequate PRT (protection) means and methods when implicating of the TXY related LCP's.

The TXY and the 7TL model is transparent for all multidisciplinary 7SL COMs. This fact is basic for Internet as SYI [4]. Hence the interdisciplinary COMs[18] may have equal and interconnected 7TL ESY, but with different disciplinary dependent API $\in$ 7TL7. These circumstances will be taken into account when creating LCP [9].

Implementations of API's cause need of EAL according to common criteria [19] and ACR (accreditation) and its MIT (maintenance) $\in$ LCP with respect to particular deontology's requirement policy.

A general example to be EAL and ACR for a particular implementation is given in Ref. [20].

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Journal of Communication and Computer 11 (2013) 1381-1395

Geolocation and Verification of IP-Addresses with Specific Focus on IPv6

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Received: October 05, 2013 / Accepted: November 15, 2013 / Published: November 30, 2013.

Abstract: Geolocation, the mapping of a network entity with its geographical position is used frequently in today's Internet. New location aware applications like e-commerce, web site content and advertisements are just some examples of what has appeared since the last couple of years. Regarding network security, geolocation also has a significant impact, since it offers possibilities for advanced network security (e.g., including sophisticated geo-based attack correlation/classification). However, determining the physical position of a network entity is challenging, as there is no inherent relationship between an IP address and its geographical location. In addition, with the introduction of IPv6, the address space is enhanced by a factor of 296, making the process far more complex in comparison to IPv4. Although numerous techniques for geolocation are existing, each strategy is subject to certain restrictions. Therefore, this publication illustrates and evaluates different approaches of geolocation. Furthermore, strategies to obtain additional information related to the location of IP addresses are examined. After considering procedures how to verify the achieved data and following the ideas of Endo et al., we are designing an architecture for a combination of different methods for optimized geolocation. Finally we introduce and evaluate our proof of concept called geolabel, a tool capable of mapping IPv4 as well as IPv6 addresses to certain geographical locations on a country level.

Key words: IP geolocation, IPv6, prosecution of computer fraud, attack attribution, network analysis.

1. Introduction

Within the Internet, addressing a host or an entity in general is nowadays almost exclusively done by the use of the TCP/IP protocol suite and here especially with the use of the IP (Internet Protocol) and the corresponding address (also called IP address, respectively IP).

1.1 Problem Statement

The IP address space of the internet is maintained by the IANA (Internet Assigned Numbers Authority) which in turn subdelegates its responsibility—depending on the geographical location to five so called RIR (regional internet registries). In return the RIRs are assigning smaller address ranges to different LIR (Local Internet Registries), NIR (National Internet Registries) as well as ISP (Internet Service Providers) [1]. Latest at the level of the ISPs, the hierarchical allocation of IP addresses becomes far less stringent. ISPs are given a high level of freedom on how they like to allocate their addresses to their customers. So, very often, different methods are in place. In addition, larger organizations such as Apple or IBM have their own address block (in case of Apple the block 17.0.0.0/8). This can lead to the fact that, within a few square meters, completely different IP addresses resp. IP addresses of different address blocks, depending on the ISP of the user, are in place. An obligation to publish details about the geographical distribution of IP addresses however does not exist at this level.

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1.2 Examples for Geolocation

Content Localization: The main application for geolocation is content localization. An example would be someone who types the word "cars" into a search engine and only receives results on cars in the local area [2]. Geolocation allows to present content dynamically in different languages or to provide the local weather forecast. Another field of application is targeted advertising for placing ads based on the estimated geographical origin of a user.

Network management and routing: In the field of academic research and for ISPs, geolocation helps to simplify network management and supports network diagnostics, for instance to detect routing anomalies. Furthermore, it is a key enabler for efficient routing policies, traffic labeling and load balancing. content delivery networks optimize the load balancing between their servers and provide better traffic management for downloads based on information gained through geolocation.

Network security: New location aware applications like e-commerce, web site content and advertisements are just some examples of what has been appeared since the last couple of years. Regarding network security, geolocation also has a significant impact, since it offers possibilities for advanced network security (e.g., including sophisticated geo-based attack correlation/classification):

Currently, due to the way the internet works, attacks can be executed from nearly everywhere. However, for an attribution, besides knowledge of logical addresses (e.g., IPs and Ports), knowledge about geographical addresses is also very important—the origination of an attack. Thus, geolocation is a prerequisite for criminal prosecution, especially in the context of a Cyber War, in order to be able to trace back an attacker (ex post investigation/forensic). As a recent study from the security company Mandiant[3]—claiming to analyze China's Cyber Espionage Units—proclaimed, "a large share of hacking activity targeting the US could be traced to an office building in Shanghai". Although the Chinese government has denied the accusations [4], the political pressure on China from the US continues. In return, it also seems that the US government has been hacking Hong Kong and China for years [5]. Both examples show how important an attribution in cyber space is and thus the rising importance of geolocation to support attribution. Geolocation is also a necessary condition for identifying and examining the network structure of the opponent in order to (1) counterattack (for example in a Cyber Conflict) and to (2) finally bring down the attack. Although numerous techniques can be used to scramble the real IP address of an attacker (e.g., NAT (Network Address Translation), proxies, anonymizing networks like TOR or the use of Bots, which are under control of the attacker), here, tracing and locating the geographical position can also support subsequent activities like isolating a system. Besides that, Geolocation can also be used very successfully to increase the security of a network during its operation mode (i.e., before an intrusion actually has taken place; ex ante).

Based on attacks detected (e.g., by intrusion detection systems such as snort), a correlation of these attacks with new connections is possible as well. Thus as a consequence, new connections originating from a location very close to where a recent attack was launched may be inspected in more detail in comparison to normal network traffic. Analog to grey listing in emails, geolocation allows to (1) correlate attacks detected with new connections (attack correlation) and as a consequence (2) to classify traffic a priori as more suspicious (thus particularly allowing to inspect this traffic in more detail, for instance performing a deep packet inspection on this traffic while the regular traffic is only inspected based on the analysis of flows).

1.3 Structure of the Publication

The aim of this publication is to design a method for advanced geolocation of IP addresses with specific

focus on IPv6. Following the idea of Endo et al. [6], this publication tries to overcome shortcomings of existing approaches with a combined solution of different methods.

The paper is structured as follows: A short overview of state-of-the-art geolocation techniques and tools is presented in Section 2. Thereafter, our architecture is illustrated (Section 3) as well as the corresponding Proof of Concept (Section 4), before an evaluation is performed in Section 5. Finally, Section 6 contains a Conclusion and Outlook.

2. Related Work

This section starts with giving a brief overview of the differences of IPv4 compared to IPv6. After that, an overview of geolocation strategies, including a brief summarization regarding signification and eligibility in respect of IPv6 is given.

2.1 IPv4 versus IPv6

The main addressing scheme in recent networks, including the global Internet, is based on the Internet Protocol. The most prevalent version IPv4 is mentioned in RFC 791 [7].

According to information from 2010 [8], about 47.3% of the IPv4-address space is allocated to the United States, followed by 39.7% for the rest of the top 15 countries of the world. This is mainly due to the historical development [9]. Hence, there is only 13% of the whole IPv4-address space left for other countries as well as for future services, where more and more devices will communicate with IP [9]. Consequently, in February 2011, IANA allocated the last blocks of IPv4 addresses.

RFC 2460 [10] describes the next generation of the Internet Protocol, known as IPv6, which is an evolution of its predecessor with focus of keeping the tried and trusted, and to overcome the weaknesses of version four. Thus, scalability and flexibility is given priority to address the expansion rate of the Internet as well as the requirements of current and future services [9]. Amongst others, main new features of IPv6 include [11]:

- Increased address space (from 232 addresses to 2,128)
- Simplifying and improving the protocol frame (header data), which relieves routers computational effort
- Stateless Address Autoconfiguration (SLAAC) of IPv6 addresses; stateful methods such as DHCP (Dynamic Host Configuration Protocol) are unnecessary when using IPv6
- Build-in support of Mobile IP and multihoming
- Implementing IPsec in IPv6 standards, which allows for encryption and verification of the authenticity of IP packets (but not mandatory any longer)
- Support of network technologies in terms of quality of service and multicast

2.2 Existing Methods for Geolocation

Endo et al [12] divides geolocation approaches in two main categories:

- IP address mapping based strategies (passive);
- Measurement based strategies.

This corresponds with other classification efforts, e.g., Dahnert [13] and Eriksson [14]. Padmanabhan etal. [15], whose work is to be considered as the first investigation on IP address geolocation, describes three different categories which nevertheless can be classed in those mentioned above [16].

2.2.1 Passive IP Address Mapping Based Strategies

Usually approaches based on IP address mapping are relying on lookups against databases without direct interactions involving the target system [12, 17]. Relating examples are the Domain Name System (DNS), datasets maintained by the five RIRs or analysis of BGP (Border Gateway Protocol) message (see below). This can also be done by crawling websites and extracting associated geolocation information [18].

- Geolocation Databases:

The use of geolocation databases (also known as geoservices) for mapping a given IP address to a physical location is common for services relying on coarse-grained estimations only. Geoservice providers like MaxMind [19] or Quova [20] offer their products either for free or commercial use, whereby commercial ones are more accurate [21, 22]. The location estimation is performed by looking up a given IP address in the corresponding datasets. Hence, accuracy, reliability and scope depend on the geoservice provider [21-23]. Most providers seem to use exhaustive tabulation of public as well as private data received through cooperating ISPs [15, 24]. However, due to the lack of concrete knowledge how the datasets are collected and the missing large scale ground-truth, an evaluation is difficult [23]. In addition, the algorithms and methodologies employed by the providers are proprietary; as a consequence, accuracy and credibility of such services has to be considered as questionable [22, 25, 26]. Nevertheless different empirical studies [21-23] have proven an accuracy of geodatabases from 96% up to 98% at country level.

- Regional Internet Registries:

Information about which RIR is currently maintaining a certain IP address block can be obtained by downloading the latest delegations. These files are also indicating, besides Autonomous System Number (ASN) and IP version, related geographic data on country level. More detailed intelligence about particular addresses respectively ranges is available by using the Who is protocol [27]. The client application Who is named the same way and integral part of each common OS. Querying a RIR for a given IP typically results in information like relating IP range, customer respectively organization details, point of contact as well as listing country, city, zip codes and further geographic details. Several approaches using such data have been published taking advantage in terms of Geolocation. NetGeo [28, 15], which uses a database build by Who is records as well as ASN (to map IP addresses onto geographic locations [12]), is one example.

- Domain Name System:

In addition to querying the databases of the five RIRs, the Who is client application can also be used to extract geographic information through the Domain Name System [29], which is a worldwide hierarchical system for mapping FQDN respectively domain names to IP addresses [17]. In comparison to the RIRs, there are no central regional administrations. Since the name space is divided into categories such as "Generic top-level domain" (gTLD) or "country code top-level domain (ccTLD)" and structured in a hierarchical way, queries have to be performed along this hierarchy, resulting in location information as well as further intelligence like organization, nameserver (valuable starting point for obtaining further intelligence) or point of contact [17, 30]. Another way to benefit from DNS in terms of Geolocation is the approach published in RFC 1876[31]. In his experimental paper "A Means for Expressing Location Information in the Domain Name System" [31] Davis proposes to add geographic data such as longitude, latitude and altitude within a new DNS resource record, called LOC record. Although this record is not widely established, it still holds information according to the location of a relating (sub) network or host. Since this may be a security risk, accuracy and reliability are depending on the responsible administration [31, 32].

- GeoCluster:

GeoCluster divides the entire IP address space into blocks or clusters. The basic assumption is that all IP addresses of a cluster can be found in the same region. Thus, based on the allocation of a cluster to a geographic region, the actual location of the destination system is suggested. Consequently, in order to assign a logical address to a cluster, extensive information on the general distribution of the IP portfolio is required. This information is obtained by the evaluation of BGP (Border Gateway Protocol)

routing tables/BGP address prefixes, Who is databases and information gathered from other sources such as ISPs or registry data from Service Providers. Due to the fact that the records of the databases are usually not checked intensely for correctness, a deliberate falsification is possible. The same applies to the Who is protocol. A mapping of a single IP to a precise location is also not easily possible, because usually only the address of the headquarters of the owner is deposited. This in turn brings no benefit if the corresponding autonomous system is geographically widely distributed.

2.2.2 Active (Measurement-Based) Strategies

In comparison to strategies based on IP address mapping, measurement-based approaches are inferring the approximate geographical location of a host, either through active delay measurement by probing the target system, or passive traffic analysis which does not insert additional packets [25]. To be successful, passive techniques require appropriate measurement equipment [33] as well as a traffic generating target systems. Furthermore, it is necessary that this traffic passes installed monitoring systems [17].

- GeoPing:

Common approaches like GeoPing [15] are working with well known location information of reference hosts, also called Landmarks or Vantage Points [12, 15]. GeoPing is a method that utilizes the correlation between latency values (such as Round Trip Time; RTT), and a geographical distance [34]. The existence of this relationship is a fundamental part of the GeoPing algorithm and at the same time represents a major challenge. In contrast to conventional opinions, that such a correlation does not exist, Ziviani et al. confirm their very existence [35]. The conclusion to the geographical position of a host is done using so-called landmarks (entities with known location). For this purpose, the minimum RTT of the client to the landmarks is measured and the results are then transferred to a map (Fig. 1).

The granularity of the results depends largely on the amount and location of usable landmarks [35]. Also distortion caused by, for example, routing loops, the last mile and safety aspects represent fundamental problems in locating an IP address. The accuracy of the results provided in GeoPing is limited to a discrete solution space, which in this context means a concrete landmark and not a region. GeoPing has an important shortcoming, since it relies on a discrete set of possible geographical locations. To overcome this, techniques like Constraint-based Geolocation have been introduced [36], which are using multilateration and are resulting in continuous reliability areas for position estimation.

- Constraint Based Geolocation:

CBG (Constraint Based Geolocation) was developed to deal with the problems of a discrete solution space for the localization, using landmarks (see GeoPing) [6]. In "Constraint-based geolocation of internet hosts" [37] Gueye et al. provide an approach based on multilateration (Fig. 2), where the position of a host is also determined based on the distance to known landmarks.

Here, a continuous solution space is achieved by using two values: A minimum and a maximum distance. Based on latency measurements of signals in fiber optic cables as well as the assumption that up to the last mile (respectively satellite links) almost all lines are made of fiber, the theoretical minimum distance is assumed to be

$$\min = \frac{2}{3}c$$

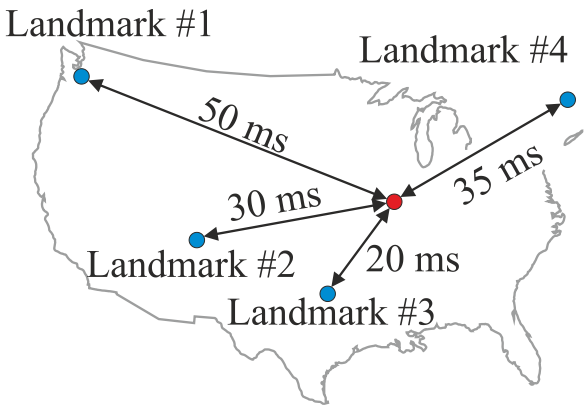

Fig. 1 Functionality of GeoPing.

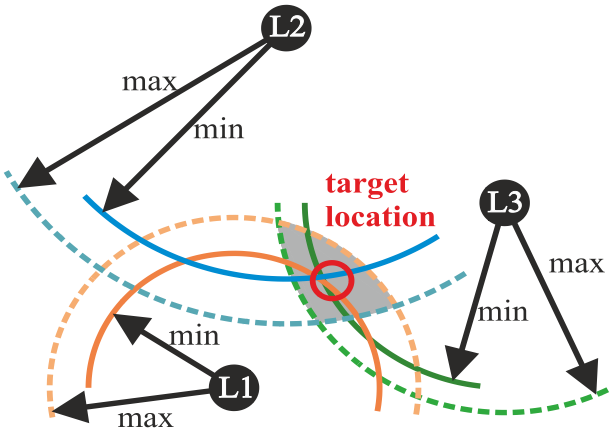

Fig. 2 Multilateration used in constraint based geolocation [38, 39].

where, c is the speed of light [38] (represented in Fig.2 by complete circles), the maximum distance is represented by

$$\max = c$$

(represented in Fig. 2 with the use of dashed circles).

The intersection over all discovered circular functions (minimum and maximum distance) is used to determine a geographic region whose center is assumed to be the exact position [37]. CBG deliberately makes an overestimation of the upper limit to ensure that the solution space is not empty. This, however, at the same time increases the intersection and thus the potential target area. Accuracy is influenced by the number of available landmarks [35] and their positions. A fundamental problem in this case is firewalls, proxies and Intrusion Detection Systems. Since CBG exclusively uses Ping-based methods to determine the delay, it can be assumed that many measurements are faulty.

2.2.3 Hybrid Approaches

Basically, hybrid approaches are combining delay measurement and IP mapping-based strategies to increase accuracy and reliability of the location estimation by overcoming the respective general limitations.

- Topology Based Geolocation:

TBG (Topology Based Geolocation) is an evolved variant of CBG, also taking topological aspects into account and thus increasing the accuracy significantly.

TBG is only an extended version of the CBG-algorithm and thus raises the same problems. In addition, the reduction of errors is done at the expense of performance.

- Octant:

Octant is a modular framework for geolocation, which uses a variety of geometric curves, known as Bezier curves, to determine the physical location of a target system, as well as positive and negative conditions [6, 40] (Fig. 3). The framework, developed by Wong et al. [40], was built on the results of TBG and extends this approach by using network nodes of the path towards the client as additional landmarks. The modular design enables octant to formulate additional constraints that can limit a possible geographic region significantly.

These constraints are based on collected demographic data, for example, and may limit the location of a possible site to inhabited areas. Other possibilities are the introduction of information from RIRs and the use of Geoservice providers such as MaxMind or Quova. Nevertheless, also Octant has the same problems TBG or CBG have.

2.2.4 Geolocation IPv6

In general, IP mapping-based as well as measurement-based approaches can be applied for geolocating IPv6 addresses, since the basic principles are protocol independent. Thus, the same limitations apply. Considering the enhanced address space of IPv6 by factor 296 and new introduced features, certain further constraints have emerged. The larger

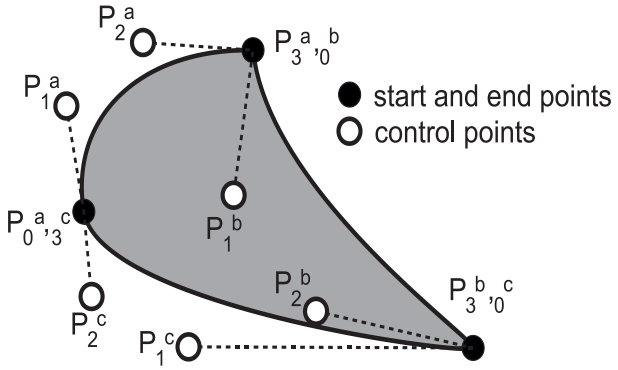

Fig. 3 Octant-Bezier Graph [40].

address space itself has no direct implications from the point of Geolocation. However, due to SLAAC and a discontinuity of DHCP, the distribution of IP addresses is different in comparison to its predecessor. In combination with the abolishment of NAT, an opportunity to track a particular host is offered. Basically this is possible, since the Interface Identifier, a part of the IPv6 address, is partly derived from the MAC address of the corresponding network interface[9, 17]. This problem has already been addressed by randomization, although it is not common for every device and implementation [41, 42]. Considering that, according to Trostle et al. [41] an IPv6 address narrows the approximate physical location of its relating host to at least city level.

2.2.5 Overview of Methods and Approaches

Table 1 provides a brief overview of methods and approaches for geolocation. Column one lists some of the previously discussed methods. The second column indicates whether the approach relies on the use of landmarks. The third column indicates whether the approach uses active/passive methods or a combination (hybrid). The fourth column provides information about the solution space. Column number five indicates, whether the approach is suitable for IPv4 and/or IPv6. Finally, resources needed referring to technical (amount of devices, knowledge etc.) as well as economic aspects are listed in column six.

2.3 Evaluation of Related Work

Performing an evaluation of the approaches presented is not easy (Table 2). This is mainly due to the fact, that (1) not all of them publish information about the corresponding accurateness and (2) the source code is not publicly available. Since NetGeo was officially discontinued in 1999 and thus is no longer developed and—as a consequence—is no longer fully available as a web-based solution, this approach is no longer considered for further considerations within this paper [43, 44]. Due to the lack of access to the information needed, GeoCluster and GeoTrack are also not considered within the architecture and the corresponding Proof of Concept (PoC) [34].

3. Overview of Our Architecture

The previous section has shown that each strategy is subject to certain restrictions. e.g., the accuracy is too low, a complex infrastructure is needed for the execution of the programs or no selection of active or passive measurements is possible. Following the idea of Endo et al., we already presented a new algorithm which combines several geolocation techniques to increase the accuracy [45]. The algorithm is able to

Table 1 Overview of Geolocation approaches.

Method	Landmarks required	Passive/active/hybrid	Solution space	IP version	Resources/effort
Geoservices	No	Passive	Discrete	4 & 6	Middle
Address block based	No	Passive	Discrete	4 & 6	Low
Who is RIR	No	Passive	Discrete	4 & 6	Low
Analysis of FQDN	No	Passive	Discrete	4 & 6	Middle
DNS LOC record	No	Passive	Discrete	4 & 6	Low
Who is DNS	No	Passive	Discrete	4 & 6	Low
GeoCluster	No	Passive	Discrete	4 & 6	Middle
GeoTrack	No	Passive	Discrete	4 & 6	Middle
NetGeo	No	Passive	Discrete	4	Low
IPv6 IP-LOC	No	Active/passive	Discrete	6	Middle
Pure delay measuring	Yes	Active/passive	Discrete/Continuous	4 & 6	High
CBG	Yes	Hybrid	Continuous	4 & 6	High
TBG	Yes	Hybrid	Continuous	4 & 6	High
Octant	Yes	Hybrid	Continuous	4 & 6	High

Table 2 Evaluation of related work.

Method	Localisation level	accuracy
IP2Geo (GeoPing, GeoCluster, GeoTrack) [46]	Country/ISP	98%
	Region	75%
	City	63%
CBG [37]	Western europe (Median error)	below 25 km
	U.S. (Median error)	below 100 km
Octant [47]	Median error	22 miles
Structon [48]	Province	93.5%
	City	87.4%
Our Approach [45]		
Paranoid Mode	Country	99.78%
	City	87.57%
Regular Mode	Country	99.78%
	City	90.49%

locate IPv4 addresses with a high accuracy of 99% on country level, outperforming current approaches (Table 2). Because of the (1) usage-limitation to single IP addresses and (2) the restriction to IPv4 addresses, it was not an appropriate solution for building comprehensive datasets based on IP blocks or ranges, nor a future-oriented solution (in terms of IPv6). Therefore, we present a new algorithm for the Geolocation of IPv6 addresses and IP ranges.

3.1 Components of the Algorithm

Our new algorithm is built from components as follows:

3.1.1 Geodatabases

Since geodatabases are commonly proprietary and the methodologies employed by geoservice providers (to build and maintain them) are neither clear nor publicly available, their consistency and accuracy is considered questionable [49]. But according to Poese et al. [22] such datasets are providing correct geographic locations at country level in 96% to 98% of the cases, at least in terms of IPv4. Additional other studies have revealed similar results [23, 21]. Regarding IPv6, to the best of our knowledge, no comprehensive research, except Zander [50], has been published. But even in this case, it can be assumed that at least on a country basis, those sets are providing correct location estimations depending on the geoservice provider Although 96% to 98% (for IPv4) is quite high, we have decided to crosscheck the information with other geographic data in order to improve the results.

The former PoC uses four geodatabases for a first coarse-grained location estimation and to limit the possible solution space by restricting further steps to particular countries. Therefore, it is obvious to use the same geoservice providers (MaxMind, HostIP, IP2Location and IPInfoDB) again [19, 51-53]. However, current investigations have shown that IP2Location and IPInfoDB are now under the same administration and therefore provide the same results (IPInfoDB uses the IP2Location Lite version and refers to the IP2Location Commercial version) [54]. Moreover, even the free databases are only available after a registration, which was not possible during our work, because neither a registration email nor further information could be obtained.

HostIP, a database mainly relying on voluntary information, has been evaluated as less accurate than the other ones [22, 23] and thus has the lowest influence on the location estimation within the former PoC. As the database is not available in the Internet any longer, HostIP is therefore not presenting a suitable alternative. In comparison, MaxMind has been evaluated several times and is also the only provider which was analyzed in terms of IPv6 [50]. In addition it “is one of the pioneers in geolocation, founded in 2002, and it provides a range of databases”[55] as well as monthly updates and APIs for different programming respectively script

languages like Perl and C.

Because of the lack of free and appropriate alternatives, MaxMind is now the only geoservice provider left for an adaption within the scope of the PoC. In addition, MaxMind provides different levels of accuracy, ranging from (1) country to longitude and latitude, and (2) free to commercial sets. Although the free databases offered by MaxMind are less accurate than the commercial ones, studies have shown that this difference is slightly lower than expected [21-23,50]. Keeping this in mind as well as the objectives of our work, the free databases—as shown in Table 3—are used within the new PoC.

3.1.2 Databases of RIRs

As already stated, a crosscheck is used within our approach to improve the results. Therefore, after the analysis of the IP address (based on geodatabases) is performed, data of the RIRs is used for the verification of the results. Therefore, the cost-free Who is-service is integrated into the algorithm. Unfortunately, the different RIRs are using different query and output schemes. Because of that, it must be differentiated where the address is registered to execute a correct direct query. Pattern matching and regular expressions are used to analyze and extract the geoinformation from the result sets.

3.1.3 Code Databases

For the further analysis of the FQDN (fully qualified domain name), the algorithm is using code databases. Four types of such databases are available: City-, regional-, airport- and radiobeacon-codes. For the implementation, cumulated databases of the IATA (International Air Transport Association) and very high frequency omnidirectional radio range (VOR) are used. In addition, beacon codes are considered, too. Here, the network entity, the primary DNS server identified by the Start of Authority (SOA) Record and the hops in the catchment area of the target address identified by route tracing are examined. Therefore, the country code of the targets (queried from one of our databases) is used to narrow down the results. Each FQDN is split into its individual segments with the help of pattern matching and regular expressions. The verification of the geolocation based on code-databases is the last step of the process. In order to merge the output of the three components of the algorithm, different weightings are used based on the concrete usage of the algorithm (see below). In particular, three basic modes are implemented, whereof two are presented in more detail in Section 4: create and verify.

3.2 Sources of Error

Because of the heterogeneity of the different databases and information sources, different errors are possible. On the one hand, the transfer of millions of records into a common format is nontrivial. On the other hand, other aspects have to be considered, e.g., failures when querying the RIR databases or errors in the trace route runs. In detail, different sources of error in the weighting and verification process are:

3.2.1 Geodatabases

As different empirical studies have shown, geodatabases are by far not complete [56-59]. Deliberate or unwanted falsifications are possible within the data sets. As HostIP for instance is filled entirely based on voluntary input, this is particularly a risk for corruption. By using multiple verification steps, as used in our algorithm, different results can be recognized and attenuated.

Table 3 Overview of used MaxMind databases (date: July 13). GeoLite City IPv6 is currently in beta state.

Database	Records	AS Provider	IP Blocks/ranges	Country
GeoLite City	1 999 247	Yes	Yes	Yes
GeoLite City IPv6	15 095	Yes	Yes	Yes
GeoLite ASN	197 447	No	Yes	No
GeoLite ASN IPv6	12 651	No	Yes	No

3.2.2 Databases of RIRs

The databases of the RIRs can have errors or can be manipulated as well. Also, there is no standardized query. This strongly hampers the automatic evaluation of addresses.

3.2.3 Code Databases

The most important problem arising by the use of code databases is the overlapping of information. Especially airport—and radiobeacon-codes can have many overlaps among each other.

Therefore, it is recommended to use the country code as the precondition before the verification process (with the code databases) is performed (as done in our PoC). This may lead to additional errors, because a preliminary containment is required.

4. Proof of Concept

Within this section, the PoC (called geolabel) for the Geolocation of (IPv6) addresses and IP ranges is presented.

4.1 Program Modes

Two basic program modes are available to cover the requests for assignment, namely:

- Create: The mode create is one of the three basic features. It is responsible for obtaining all required resources as well as querying the RIR according to the prefix. In addition, the responses are analyzed in terms of location information and further intelligence.
- Verify: The verify mode is executed after the create mode and tries to verify the extracted location information by comparing it with different other resources like for example the geodatabases provided by MaxMind. Hereby, the weighting algorithm is applied to respect the significance of the different data sources (see below).

4.2 Weighting Algorithm

With regard to geolocation, the verify mode is quite important, since it compares different sources according to their location estimation. Here, each source has to be weighted according to certain aspects: The first stage of the verify mode is to obtain all needed files, like the MaxMind GeoLite databases. Afterwards all sets are correlated, processed and stored. The data is then used to update missing records. Therefore a Patricia-Trie is used, which allows to compare IP ranges bit by bit.

Geolabel provides certain parameters which can be used to define the amount of bits to be shifted. The pitfall at this point is that by shifting bits, correct IP prefix to ASN mappings cannot be guaranteed. Hence this has to be included in the weighting algorithm. After the updates are done, all tables are correlated to build a dataset for each IP range (extracted in create mode). One set consist of an IP range, the relating address prefix and four country codes obtained by the following sources: To determine which country may be inferred for the location estimation of a certain IP range, the country code from each source is considered individually. Based on this, several variables are used to calculate an estimation value for each estimation according to the source, Table 4. Since it has been demonstrated that geodatabases are accurate by 96% up to 98% [22], the lower bound is chosen to express this fact.

All country estimations are analyzed according to their validity or if they are equal to EU (European Union) or AP (Asian Pacific), which causes a depreciation, since both are usually only used when a

Table 4 Influence of different variables on the estimation value according to the source.

Source	Country	Netmask	Bit shifting	Rank
Whois queries	Yes	Yes	No	3
MaxMind geodatabases	Yes	No	Yes	4
Relating address prefix	Yes	Yes	Yes	2
Relating ASN	Yes	No	Yes	1

specific country code has not been designated (for instance satellite connections or the IP range is currently not assigned). For the codes obtained by Whois queries and address prefixes, the prefixlength respectively the netmask will be taken into consideration. According to Freedman et al. [60] prefixes with short netmasks tend to be more geographically dispersed than longer ones. Considering that, a longer prefix has less influence than a shorter one. All sources which are updated or correlated by bit shifting are weighted additionally, since this may cause wrong assignment. Thus the amount of bits shifted has to be taken into consideration. To determine an overall country inference including an overall estimation value, all obtained country codes as well as the calculated estimations values are correlated. This is done according to the following cases:

(1) Decision by majority;

(2) If two solutions are possible (parity), the decision is made by taking into account the weighting factors;

(3) If there is no consensus at all, the decision is made according to the rank of each source, whereby the geodatabase has the highest one and thus is chosen.

All countries which are obtained, but not used for the overall country inference, are marked and stored as optional solutions, but without any rating. Thus the solution space is increased.

After that, the analysis of the hops can be done. If it was possible to resolve the complete path, the last two hops are examined. Otherwise, the last hop which can be resolved is examined. Finally, if a VPN connection had been used, the connection is closed down and the program run is completed.

4.3 Known Shortcomings

Different studies have shown [21-23] that geodatabases are commonly based on proprietary methodologies. Thus they are questionable in terms of reliability, scalability and maintainability. Considering that "prefixes within databases are not clearly related to IP prefixes as advertised in the routing system" [22], the datasets may be corrupted by unwanted or intentional falsifications [45]. In addition, data provided by Whois may be outdated, incomplete or even hijacked [17].

Thus the obtained information has to be verified. Next to incomplete sets, malformed records have also been observed. For the lack of ground truth and concrete figures, the weighting algorithm is based on assumptions, which have been deduced from research work and studies over the past few years (see also Ref. [45, 61]). In addition, because of missing recent studies in terms of IPv6 Geolocation, the algorithm is applied for both versions in the same way.

5. Evaluation

To evaluate the accuracy of the PoC, testruns with tuples of known IP address to location mappings have been applied. Obtaining an appropriate amount of these tuples is difficult because of a missing groundtruth. Therefore, it is typically done by using personal connections to certain ISPs or other sources which are able to provide such data. Research networks are another way to obtain the information needed and thus are used as well. Two active measurement projects, Archipelago (Ark) maintained by the CAIDA (Cooperative Association for Internet Data Analysis) and RIPE Test Traffic Measurement Service (TTM) [62, 63], are publishing FQDNs as well as relating geographic positions. In addition, all monitors of the RIPE TTM project are equipped with GPS. Another source which has been identified is TOR, which provides the possibility to specify the countries where the Exit-Node is located.

The first step of the testing procedure is to build a basic dataset using the create mode for both IP versions. Afterwards, the obtained information are analyzed by using the verify mode, which results in a dataset used in the evaluation procedure. In

preparation for the evaluation per se, all testing sets have to be processed to a proper format, since the address information obtained from Ark and RIPE TTM are only provided as FQDN. Thus the IP addresses have to be queried by using the host command or dig, for instance. In addition, all verified sets are used to build a Patricia-Trie with an IP range as (primary) key and the relating country as well as optional ones as value. Next, the created Patricia-Trie was used to match all IP addresses of the evaluation set to a certain range and compared to the relating countries. If the countries are not matching in the first place, optional ones are used for further investigations, resulting in consensus or no match at all and thus no positive rating on a country level.

About 59% of the IP addresses have matched in first or second place (Table 5). While the datasets provided by Ark and RIPE TTM are considered to be accurate, TOR is still based on assumptions. Without TOR, the matching rate raises up to about 72%. But this value has to be considered carefully, because now the set consists of 163 tuples which is not enough to prove a certain accuracy. Since the results are much lower than expected, it has to be questioned what the reasons therefore are, considering the supposed accuracy of the involved geodatabases. One reason may be, that no bit shifts have been applied. There are several possibilities during the whole procedure (of creating and verifying) to adjust the amount of bits shifted and thus to increase the likelihood for a successful IP to country mapping. Another reason may be corrupt or outdated sets from MaxMind, since all tests have been conducted with the same GeoLite databases which have not been updated for over one month. Also, the reliability and accuracy of all sets based on TOR may be disputable.

As already determined, an accurate evaluation for IPv6 is not possible yet due to the lack of a comprehensive ground truth. Table 6 shows the current results according to the available test field: Therefore, the PoC has an accuracy of about 79% on country level. Considering the enlarged address space of IPv6 as well as the fact that the results are obtained without any use of bit shifting, the matching rate may be increased by applying certain bit shifts.

6. Conclusion and Outlook

Determining the physical position of a network entity is challenging as there is no inherent relationship between an IP address and its geographical location. Thus research facilities, legal authorities as well as the industry are showing an

Table 5 Evaluation result IPv4, ε describes the amount of test IP addresses, locipr describes a match in first and locoptipr second place, Ø stands for no match at all. S is the amount of sets to check against, after verify mode has been applied.

Source	ε	locipr	locOptipr	Ø
Ark	77	46	1	30
RIPE TTM	86	70	0	16
TOR	3,722	2,554	78	1,090
Σ	3,885	2,670	79	1,136
% (overall)	100	68.73	2.03	29.24
% (Ark& TTM only)	100	71.17	0.061	28.22

|S| = 6 032 219.

Table 6 Evaluation result IPv6.

Source	ε	locipr	locOptipr	Ø
Ark	23	18	0	5
RIPE TTM	36	29	0	7
Σ	59	47	0	12
% (Ark& TTM only)	100	79.66	0	20.34

|S| = 192 368.

increasing interest on certain geolocation strategies. With the introduction of IPv6, the address space is enhanced by a factor of 296, rendering this process even more complex in comparison to IPv4. Regarding IPv6 Geolocation in general, except Zander et al. [50], no comprehensive related work is available. Since the ground truth data set obtained for an evaluation in terms of IPv6 is not sufficient, it is difficult to assess the PoC in this field. Hence, without further information (e.g., how IPv6 is applied in general for instance dispersion according to IP address blocks as well as ASN), it is difficult to evaluate the accuracy of a PoC. During the process of evaluation, some noticeable problems were observed. For example, reserved IP address ranges respectively IP addresses have been identified (192.168.0.0/16, etc.) during all tests; they have been extracted from Route Views datasets obtained by CAIDA. Considering that, this implies that they are announced by BGP, which may be subject to router misconfigurations. The PoC is able to map IP addresses and ranges to a specific location on country level. Despite the accuracy problem, the PoC has several advantages towards approaches which are not based on bulk data copies. One of them is that dial-up users can also be located, since at least smaller ISPs tend to assign certain address ranges regionally. The accuracy of the developed approach is currently not as high as expected. The reasons for that may be outdated sets of involved geodatabases. Considering the different results with increased accuracy by using only ground truth from Ark and Ripe TTM, this leads also to the question if geodatabases are as accurate as they claim to be? Bit shifting may help to address the problem and lead to a significant increase of the matching rate, but this has to be analyzed in further investigations. To build further ground truth, already existing addresses can be traced and analyzed in terms of relating nameservers. After extracting these information, the SOA as well as the last hops have to be geolocated. Since SOA and last hops tend to be geographically near to the end user [15, 64, 65], it can be inferred that they are located near the addresses of the ground truth set. This procedure may be applied recursively on every address which is taken into consideration.

Acknowledgments

The authors wish to thank the members of the chair for Communication Systems and Internet Services at the Universitat der Bundeswehr Munchen, headed by Prof. Dr. Gabi Dreo Rodosek, for helpful discussions and valuable comments on previous versions of this paper. The chair is part of the Munich Network Management Team.

In addition, special thanks go to Lars Stiemert, who made a significant contribution for this publication with his high-grade bachelor's thesis and the subsequent outstanding master's thesis.

This work was partly funded by Flamingo, a Network of Excellence project (ICT-318488) supported by the European Commission under its Seventh Framework Programme.

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Journal of Communication and Computer 11 (2013) 1396-1402

An Advanced Implementation of Canonical Signed-Digit Recoding Circuit

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Received: October 17, 2013 / Accepted: November 15, 2013 / Published: November 30, 2013.

Abstract: The CSD (canonical signed-digit) representation is used in some areas which need high-speed arithmetic operation, such as DSP or digital filter. Many recoding algorithms and implementations are widely studied, however, most of those convert from a two's complement number into its CSD representation. Authors have proposed the recoding algorithm and several useful implementations from arbitrary radix-two signed-digit number representation into its CSD representation. In this paper, we propose a new structure of the recoding circuit derived from existing implementations. We also show that the proposed circuit is 10% faster than the existing circuits for 32 and 64 digits.

Key words: Canonical signed-digit number, recoding algorithm, digital arithmetic.

1. Introduction

The signed-digit (SD) number system and its representation are widely used for high-speed computation such as multiplications. It is for this reason that the SD number system has a redundancy, that is, there are several different representations for a value. By reducing the number of nonzero digits in the SD number representation of an operand in multiplication arithmetic, the hardware complexity can be reduced and an improvement in clock speed may be achieved, such as digital filters [1] in digital signal processing or exponentiation in cryptosystems[2], because a large number of multipliers are used. One of the famous applications of the SD number representation is the modified Booth recoding [3]. This recoding enables to reduce the number of partial products of the multiplication.

The CSD (canonical signed-digit) representation is one of number representations in SD number system which has two main properties: (1) the number of nonzero digits is minimal, and (2) no two consecutive digits are both nonzero. Since CSD recoding algorithm was proposed in Ref. [4], many algorithms have been made to obtain a CSD representation efficiently [2, 5-18]. However, these researches convert to CSD code from two's complement number representation. Authors have proposed a CSD recoding algorithm from an SD number representation[19] and some implementations and evaluations have been shown in [20].

In this paper, we propose a new structure of the recoding circuit which combines two implementations treated in Ref. [20]. We also show that the proposed circuit is 10% faster than the existing circuits for 32 and 64 digits.

The paper is organized as follows: Section 0 introduces the SD number system and the CSD recoding algorithm from the SD number representation. In Section 0, we show some implementation schemes of the CSD recoding algorithm. Section 0 shows a new implementation which is obtained by former implementations. A new implementation is evaluated and compared with the

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former method in Section 0. Section 0 summarizes this paper.

2. SD Number System and Its Recoding Algorithm

A number X can be represented by an n-digit SD number representation as follows:

$$X = x_{n-1}2^{n-1} + x_{n-2}2^{n-2} + \cdots + x_1 2^1 + x_0 2^0,$$
$$x_i \in \{\bar{1}, 0, 1\}$$

Where $\bar{1}$ stands for -1. A given n-digit SD number representation has a value range of $[-(2^n - 1), (2^n - 1)]$. Obviously,

$$-X = (\overline{x_{n-1}}\ \overline{x_{n-2}} \cdots \overline{x_0}),$$

Where $\overline{x_i}$ stands for $-x_i$. The SD number representation has redundancy: Three may be represented by (0011), $(010\bar{1})$, $(01\bar{1}1)$ or $(1\bar{1}\bar{1}1)$ for $n = 4$. Zero, however, has a unique representation.

In the SD number system, a converting algorithm for the CSD $(y_n y_{n-1} y_{n-2} \cdots y_1 y_0)$ from a given representation $(x_{n-1}x_{n-2} \cdots x_1 x_0)$, which we call CSD representation recoding algorithm, can be done by applying the rule (Table 1) to the digit x_i together with carry c_{i-1} and digit x_{i+1} from the least significant digit to the most significant digit.

We assume $c_{-1} = 0$ and $x_n = 0$ for converting two digits x_0 and x_{n-1} properly.

An example of the recoding process of a given $X = 1\bar{1}110\bar{1}1\bar{1}$ to its CSD representation $Y = 0100\bar{1}0\bar{1}01$ is shown in Fig. 1.

3. Several Implementations of Recoding Algorithm

In this section, we show three implementations of the recoding algorithm treated in previous section.

3.1 Implementation with Ripple Carry Method

The first implementation follows the recoding algorithm faithfully. A block diagram is shown in Fig. 2.

This circuit does not include any additional circuit to execute the recoding efficiently. Therefore, the circuit requires small area, however, the time complexity is $\boldsymbol{O(n)}$. This implies that this implementation is not suitable for large digits, such as cryptosystems.

3.2 Implementation with Carry Select Method

The second implementation is based on the CS (carry select) method. The CS method divides the $\boldsymbol{n}$-digit operand into $\boldsymbol{r}$-digit blocks. For each block,

Table 1 Conversion rules.

	$\text{abs}(x_i)$ =$\text{abs}(c_{i-1})$	$\text{abs}(x_i) \neq \text{abs}(c_{i-1})$	
		$\text{abs}(x_{i+1}) \neq 0$	$\text{abs}(x_{i+1}) = 0$
y_i	0	$-(x_i + c_{i-1})$	$(x_i + c_{i-1})$
c_i	$(x_i + c_{i-1})/2$	$(x_i + c_{i-1})$	0

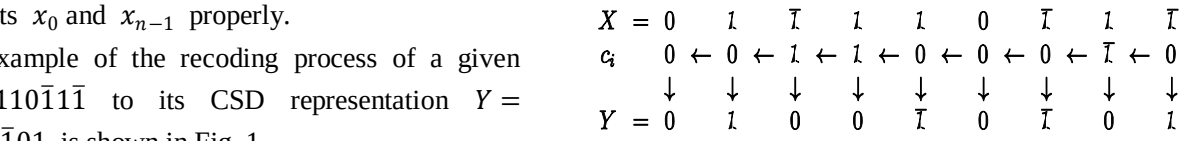

Fig. 1 An example of the CSD recoding.

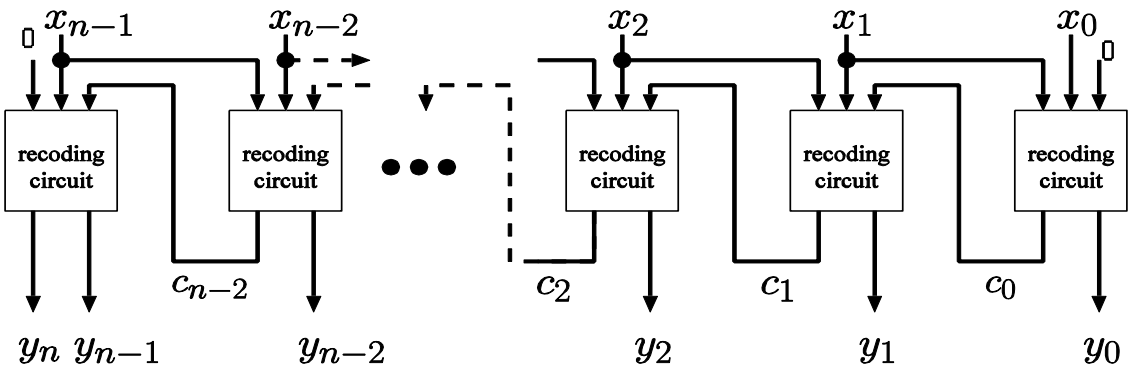

Fig. 2 A recoding circuit with ripple carry method.

except the first, two r-digit recoding circuits with ripple carry method are contained. For the two recoding circuits, one circuit has a carry in of zero, whereas the other has a carry in of nonzero. In the latter circuit, the sign of the carry can be obtained by lower two digits. All blocks are operated in parallel and each block generates a carry to the upper digit block. Each block selects the appropriate sequence of subsequent digits and carry to the upper digit block by a carry from the lower block. The time complexity is $O(\sqrt{n})$ if the size of each block is $\sqrt{n}$ and $\sqrt{n}$ blocks.

A 16-digit SD number recoding circuit with the CS method which divides 16-digit to four 4-digit ripple carry recoding circuits is shown in Fig. 3 as an example.

3.3 Implementation with Conditional Sum Method

The third implementation is based on the COS (conditional sum) method. The conditional sum method is similar to the carry select method, but the difference between two methods is the structure of each block. Firstly, the COS method divides the n-digit operand into r blocks. Each block contains a circuit for n/r-digit. Secondly, each block is divided into r blocks recursively. In carry select method, recoding circuits for each block are implemented by ripple carry method. Therefore, if we set $r = 2$, each n-digit SD number is converted by 1-digit recoding circuit and then concatenated by $n - 1$ multiplexers without carry propagation. The time complexity is $O(\log n)$. An 8-digit SD number recoding circuit with the COS method is shown in Fig. 4 as an example. In Fig. 4, each concatenate circuit is formed by two 1-digit 2:1 multiplexers (for carryout to the upper block) together with two k-digit 2:1 multiplexers (for output digits).

4. An Advanced Implementation of the Recoding Algorithm

While evaluating these implementations, we have found that the circuit with the carry select method is faster and smaller than the circuit with the conditional sum method for small input (Table 2).

In this section, we introduce an advanced implementation combining the two implementations treated in the previous section.

First we obtain short subsequences using the carry select method. Then we concatenate each subsequence according to the conditional sum method.

The conventional recoding circuit with the carry select method outputs one sequence, that is, an output with carry in to the lowest digit is zero. Therefore, we should modify the circuit with two outputs to connect the circuit with the carry select method with the conditional sum method. One of the output is a recoding subsequence supposing that at carry in to the lowest digit is zero. Another is a recoded subsequence supposing that a carry in is nonzero. A modified recoding circuit for 8-digit is shown in Fig. 5.

A 32-digit recoding circuit by using Fig. 5 and the conditional sum method is shown in Fig. 6.

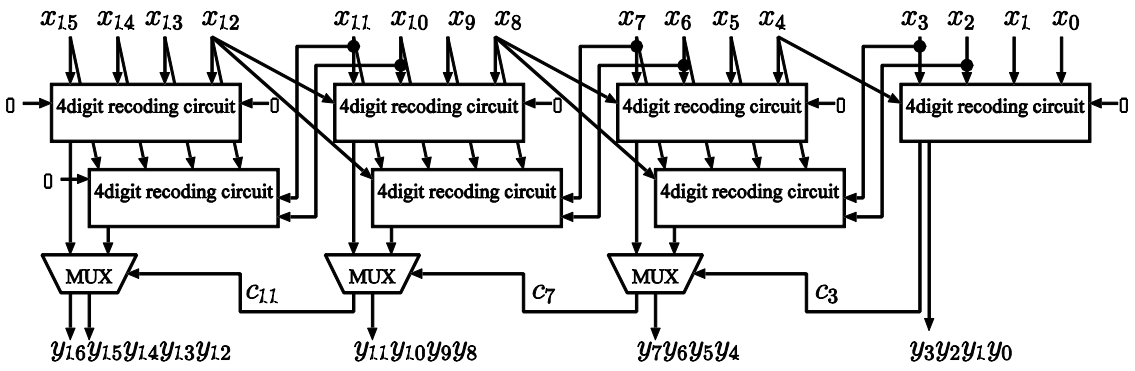

Fig. 3 A 16-digit recoding circuit with the carry selects method.

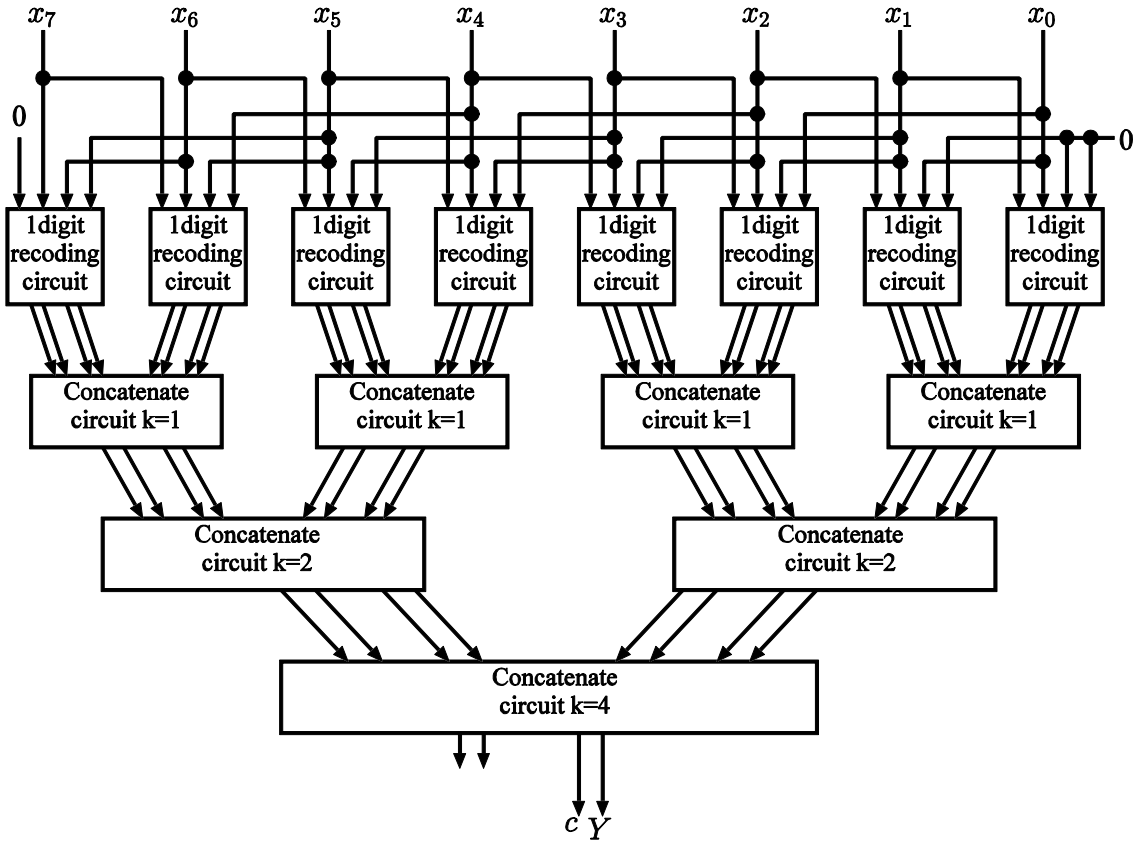

Fig. 4 An 8-digit recoding circuit with the conditional sum method.

Table 2 Area and time comparison for 8-digit recoding circuit.

8-digit recoding circuits	Area (μm^2)	Delay (ns)
Carry select	5,229.82	0.92
Conditional sum	5,442.83	1.09

Recoding steps from a 32-digit SD number $1111011011011110\bar{1}000\bar{1}0\bar{1}0\bar{1}0\bar{1}\bar{1}010$ to a CSD $1000\bar{1}000\bar{1}00\bar{1}000\bar{1}00100\bar{1}01010101010$ according to Fig. 6 is shown in Fig. 7. In Fig. 7, digit sequences with $c = 0$ mean sequences supposing that a carry in from the lower digits is zero.

5. Evaluation of the Proposed Circuit

In this section, we show the areas and delay times of three circuits treated. All of them are synthesized with Synopsys design compiler using the $0.18\mu m$ CMOS library. We have synthesized the mixed layouts for 32-digit and 64-digit. The results are shown in Table 3 and Table 4, respectively. In each row, the smallest value is emphasized.

In both circuits, we can see that a circuit which obtains $(n/4)$-digit subsequences by the carry select method and then concatenates four subsequences by the conditional sum method is fastest. For 32-digit recoding circuits, the circuit with fastest combination is 12% faster than the carry select method and 25% faster than the conditional sum method. For 64-digit recoding circuits, the circuit with fastest combination is 17% faster than the carry select method and 26% faster than the conditional sum method.

In the view of the area, a circuit which obtains 4-digit subsequences by carry select method is smallest. However, the difference of areas with the smallest one and conditional sum is less than 5%. Therefore, we may focus on the processing time rather than the area.

6. Conclusions

In this paper, we have shown an advanced implementation of the recoding algorithm to obtain a

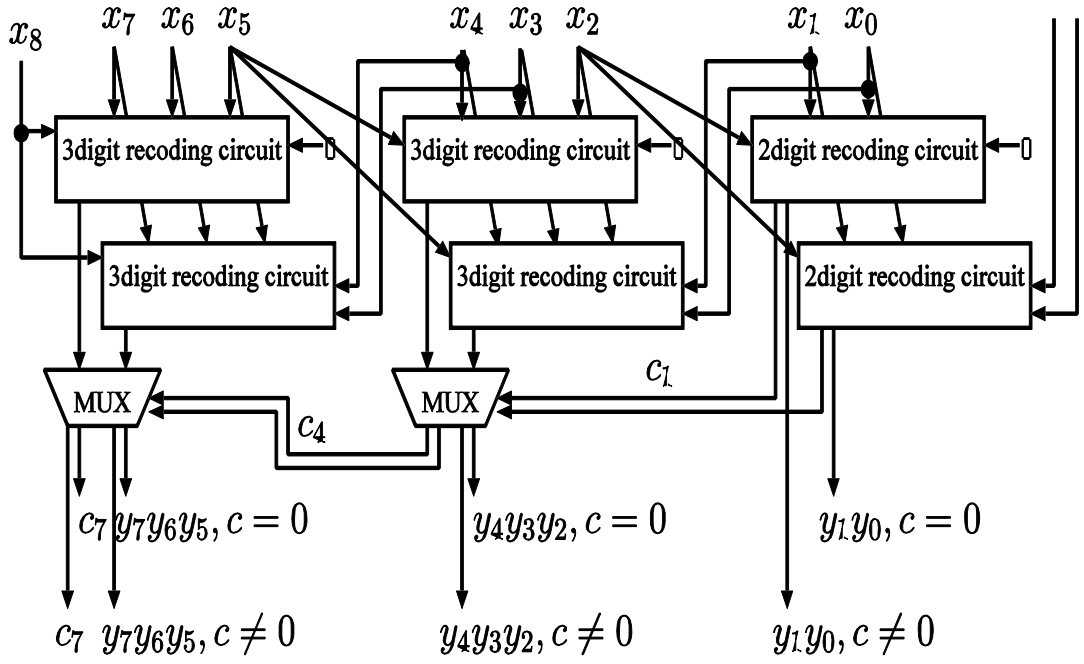

Fig. 5 An 8-digit modified carry select recoding circuit.

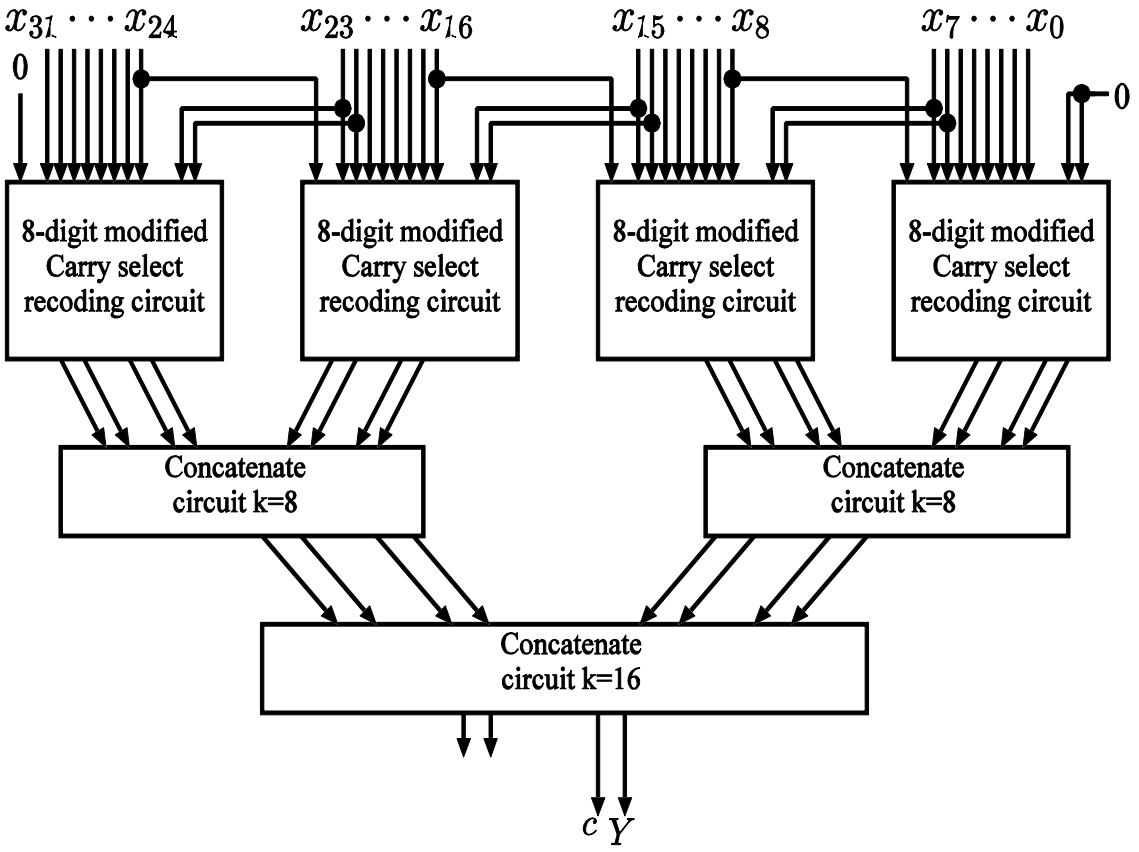

Fig. 6 A proposed 32-digit recoding circuit.

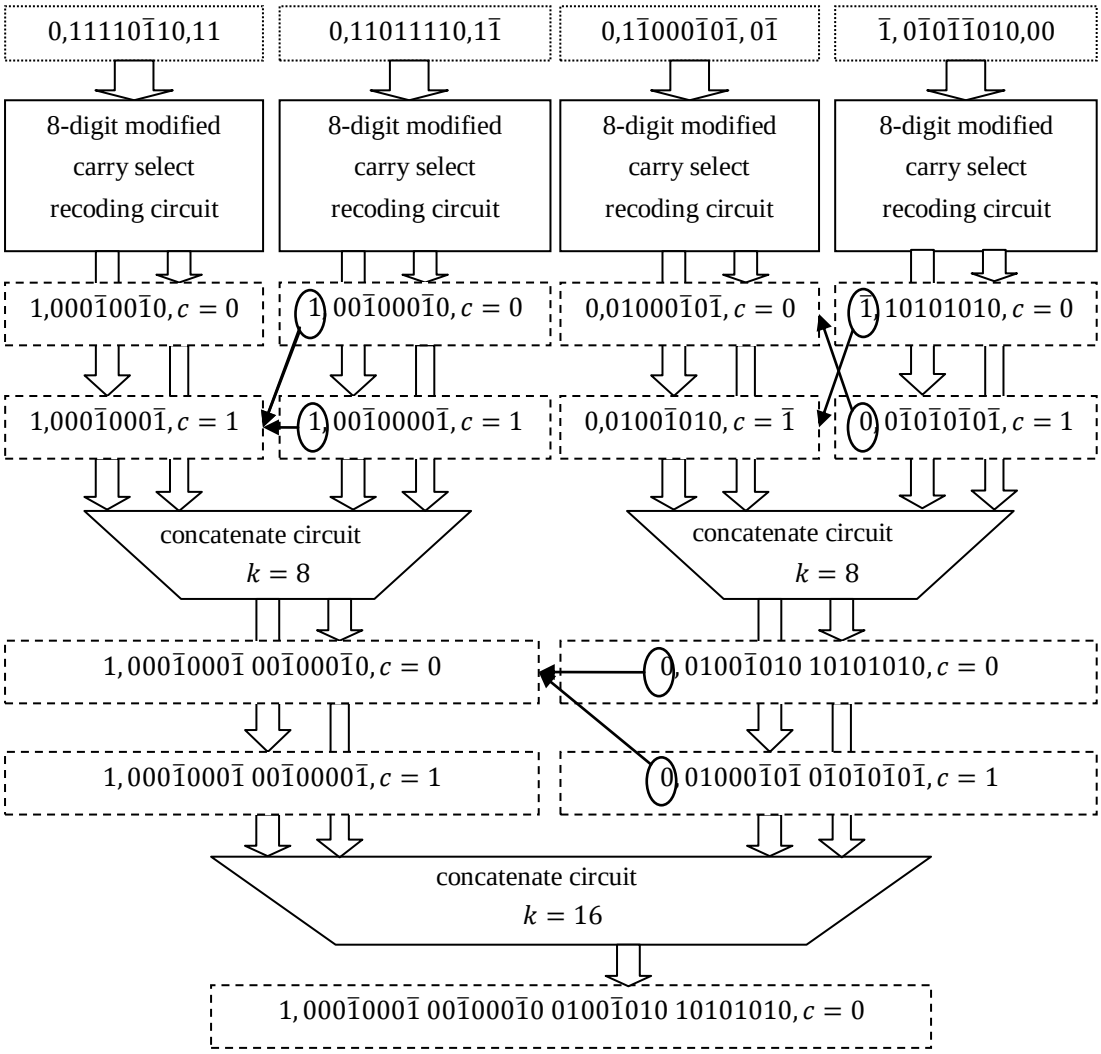

Fig. 7 Recoding steps from $11110\bar{1}1011011111010\bar{1}\bar{1}000\bar{1}0\bar{1}0\bar{1}0\bar{1}\bar{1}010$ to CSD $1000\bar{1}000\bar{1}00\bar{1}000\bar{1}00100\bar{1}01010101010$.

Table 3 Area and time comparison for 32-digit recoding circuits.

32-digit recoding circuits	Area (μm^2)	Delay (ns)
Carry select only	27,068.73	2.29
4-digit by carry select	20,754.68	2.43
8-digit by carry select	24,641.21	2.02
Conditional sum only	21,304.74	2.69

Table 4 Area and time comparison for 64-digit recoding circuits.

64-digit recoding circuits	Area (μm^2)	Delay (ns)
Carry select only	63,178.81	3.49
4-digit by carry select	35,269.06	3.93
8-digit by carry select	37,488.60	3.17
16-digit by carry select	45,184.26	2.89
Conditional sum only	37,386.81	3.93

canonical signed-digit representation from normal signed-digit number representation. The proposed circuit based on the two methods gets a better performance compared with the existing method.

Acknowledgments

This work is supported by VLSI Design and Education Center (VDEC), the University of Tokyo in collaboration with Synopsys, Inc..

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Journal of Communication and Computer 11 (2013) 1403-1409

A Comparative Study to Find the Most Applicable Fire Weather Index for Lebanon Allowing to Predict a Forest Fire

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Received: October 24, 2013 / Accepted: November 15, 2013 / Published: November 30, 2013.

Abstract: Forest fire prediction proves to contribute in preventing fire occurrence or reducing its catastrophic impacts in worst cases on human lives, properties and green forestry. Seven existing fire weather indices are studied in this paper. The aim is to find the best fitting model for Lebanon Mediterranean conditions among Keetch Byram, Nesterov, Modified Nesterov, Angstrom, Modified Keetch Byram, FMI and FWI Canadian index. Meteorological data from Lebanon are implemented for that purpose. On the behalf, a study is held on the most efficient parameters allowing to find an adapted empirical drought index to Lebanon and Mediterranean conditions in the future.

Key words: Forest fire prediction, fire weather indices, efficient parameters.

1. Introduction

Green areas in Lebanon constitute a unique value within the vicinity of an arid ecosystem in the eastern Mediterranean. These forests have covered approximately 13.5% of the total area by the year 2006. It has long supplied the Lebanese in general and the villagers in particular with diverse income sources. Vegetation serves to ensure lush pastures for beekeeping and homes to many of the medicinal and aromatic herbs.

Pine trees are considered to be products of high economic value for example, as well as other products, like coal and firewood [1].

Forests that contain precious remnants of broad-leaved trees, pine trees and evergreen trees are exposed to shrink with increasing frequency. This is due to several factors: notably the urban tide, diseases that kill them, fires, wars, climate change and human negligence, in addition to the weakness in the application of laws, policies and administrative procedures. Forest fires in Lebanon, as in other countries of the Mediterranean basin have long formed a real problem and still led to serious damage of natural resources. Also, the lack of control over the implementation of the national strategy for the management of forest fires which passed in the Council of Ministers in May 2009, and the lack of human and material resources and technical standards required all contributed to such degradation. These factors have led to a great imbalance in the ecosystem, which carry a negative impact on the lives of the surrounding communities. Fires in Lebanon recently gutted large swathes of green areas. Note that the percentage of forest cover has declined in Lebanon in recent years to 13% of the total area after it had

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constituted about 35% in the years 1960-1965, and this occurred during a short period of time, sparking concern at both the local and international levels. The risk of forestry extinction imposed to think in an urgent strategy taking real steps to prevent it [2].

Forest fire in Lebanon is considered a complex problem as it is impossible to deal with it individually at the sector level. It includes all matters related to forest management and firefighting, prevention and procedures after occurrence, which lies mainly on the administrative level in the presence of several powers dating back to more than a public administration in this issue, as on the legislative level and the implementation of laws, and the level of equipment and competences. The risk of these fires is still threatening forests of Lebanon, its environment regulations and economic growth, in spite of all the efforts made in this regard. Reports indicate an increase in the rate of fires and a rise in their intensity, which negatively affects the growth of trees and continuity, firewood products and their quality, and wildlife habitats, as well as environmental, aesthetic, cultural, economic and touristic values of forests. Nevertheless, big fires lead to material and human losses. Fires form a major cause of the destruction of forests and other green areas in the Mediterranean basin in general, and in Lebanon in particular, causing economic losses and human and environmental toll. "The risk of forest fires in Lebanon" map, prepared by the Association for Forests and Development AFDC in 2005 and updated in 2007, showed that fire threatens at least 28% of the total area of Lebanon (Fig. 1).

Currently, forest fires in Lebanon are closely related to prevailing climatic conditions characterized by long summer (from June until October, and sometimes afterwards) with almost zero precipitation rates, and an average temperatures exceeding 30 ℃ during the day, which reduces the moisture content of vegetation to below 5%. In these circumstances, a small spark, a still-burning cigarette or even a matchstick could be sufficient for a disastrous fire to be ignited. It is to be noted that ravines sloping and high temperatures and the dry east fall winds with high speed all contribute in making the situation even worse. Among the factors that threaten forests in Lebanon in general, fire constitutes the most dangerous factor on the level of economic, environmental and sometimes human losses. During a few hours, fires are destroying all produced by nature over the years, even centuries. Lebanon has witnessed a significant increase in the rate of fire that reached the extent of catastrophic and must pay attention to it taking practical steps to address its negative effects. This is what was observed in the month of October 2007, when erupted more than two hundred fires in less than 24 h, destroying thousands of hectares of forest and forest area and other territories. It is worth mentioning that the fire may do not eliminate the woods sometimes in full, and can create a positive

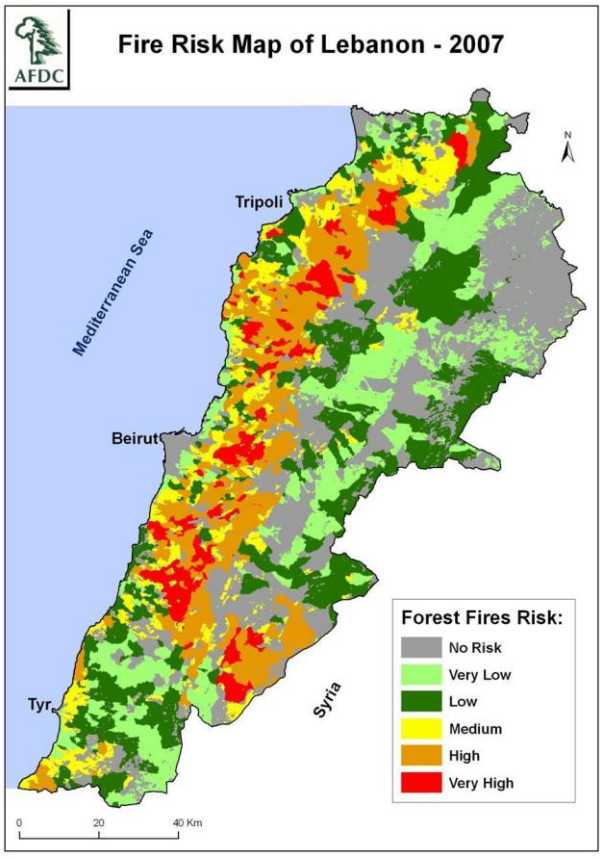

Fig. 1 Fire risk map of Lebanon-2007, AFDC.

factor if they are limited and exposed to minor spaces. The lack of information about forest fires and their causes constitute a major impediment in understanding the nature of these fires. There is an urgent need for the necessary information to determine the size of the problem and its importance in relation to decision-making positions, so as to define the priorities and procedures to be followed. So, collecting information is a very essential agent to develop appropriate strategies and policies [2, 3].

In this paper, forest fires prediction in Lebanon and Mediterranean basin is discussed. Seven commonly used all over the world; Angstrom, Nesterov, Modified Nesterov, KBDI, Modified KBDI, FMI and the Canadian Fire Weather Index FWI; are applied to Lebanese weather data collected in 2012 from Kfarchakhna station, North Lebanon. ROC (receiver operating characteristics) analysis has been used to make decision about the most applicable index for Lebanon and the Mediterranean. Many measures have been applied and interpreted to make our critical decision.

2. Area Description and Data

Lebanon, stretching along the eastern shore of the Mediterranean Sea, is characterized by a long, hot and dry summer, and cool, rainy winter. Fall and spring play transitional roles among winter and summer. In fall, temperatures tend to decline gradually accompanied by little rain. Conversely, in spring, the vegetation grows again benefiting from winter rainfalls and raised temperatures. Winter is the season of rain, with major precipitation falling after December. Rainfall is considered good but is concentrated during only a few days of the rainy season, falling heavily. The amount of precipitation varies greatly from one year to another. Cold winds usually come from Europe. The "Khamsin" hot wind blowing from the Egyptian desert, may provide a warming trend during the fall, but more often happens during the spring. Along the coast, the proximity to the sea provides a moderating influence on the climate, making the range of temperatures narrower than it is inland, but the temperatures are cooler in the northern parts of the coast where there is also more rain.

Variation of topography yields different local climatic zones. Ministry of Public Works and Transport, in the collaboration of UNDP, defined four climatic zones in Lebanon: Coastal, Western Mid-Mountain, Inland Plateau and High Mountain taking into consideration altitudes and micro-climatic trends.

In this study, North Lebanon is taken. Meteorological data are provided by Kfarchakhna station—Lebanese Agricultural Research Institute, LARI. Kfarshakhna is about 220 m above sea level. It is 25 km from the Mediterranean Sea, also 24 km from the coastal city Tripoli, and 80 km from Beirut. This region tracks climatic zone 1: Coastal [4].

The weather data of the year 2012 are introduced for the seven indices to be applied. The information about fire resides in that region was the most complicated problem that encountered, even more complex than the indices algorithms themselves. As in Lebanon, unfortunately, neither governmental nor non-governmental organizations document such data. We turned to newspapers and websites to record all forest fires day by day. And for the latter, data of only one year were used, as it is difficult to go back further in the archives.

3. Fire Indices Application

In order to forecast the risk of fire occurrence and allow fire managers to take the necessary actions in advance, many forest fire indices have been developed and tested. These indices act as important tools in evaluating regional fire risk potential over time. They have the ability of providing quantitative estimates on the possibility of a forest fire incidence. They allow taking precautions that contribute to prevent fire occurrence or reduce its consequences in worst cases. Seven commonly used indices are used to conclude

among them the most applicable index in Lebanon which is a part of the Mediterranean basin.

3.1 Index1: Keetch-Byram Drought Index

The KBDI (Keetch-Byram Drought Index), created by John Keetch and George Byram in 1968, is a measure of meteorological drought for predicting the likelihood of wildfire. It requires only few meteorological data, maximum daily temperature, total daily precipitation and the average annual precipitation.

$$KBDI_t = KBDI_{t-1} + DF \quad (1)$$

While the drought factor DF equals;

$$DF = \frac{(800 - KBDI_{t-1})(0.968e^{(0.0875T+1.5552)} - 8.3)}{1 + 10.88e^{-0.001736R}} \cdot 10^{-3} \quad (2)$$

where, T is the daily maximum temperature (^{o}C), R is the mean annual rainfall (mm), dt is the time increment (days) and $KBDI_{t-1}$ is the Keetch-Byram Drought index for time t-1. Daily precipitation decreases KBDI when 24-h precipitation is greater than 5 mm (0.2 inches) [5, 6]. Table 1 shows its scale.

3.2 Index2: Nesterov Index

The Nesterov Index is a simple fire-danger rating system that came about in 1949. It is as follows:

$$MNI = \sum_{i=1}^{W} T_i(T_i - D_i) \quad (3)$$

Where N = Nesterov Index, W = number of days since last rainfall > 3 mm, T = mid-day temperature (^{o}C), D = dew point temperature (^{o}C).

The total is calculated for positive temperatures for a sequence of days with precipitation less than 3 mm. Rainfall above 3 mm resets the index N to zero [6, 7]. Table 2 states its range.

3.3 Index3: Modified Nesterov Index

The Russian index is then modified to take into account a reduction factor. The index is calculating as follows:

$$MNI = k\sum_{i=1}^{W} T_i(T_i - D_i) \quad (4)$$

where, k takes the values of the table below, in dependence of the current rainfall Its range is found in Table 3.

The fire risk level of the modified index resembles that of Nesterov's one as when it exceeds 10,000, the risk will be extreme [6].

3.4 Index4: Angstrom Index

The angstrom index was developed in Sweden for Scandinavia. It uses only air temperature and relative humidity in its calculation and provides an indication of the likely number of fires on any given day. The Angstrom Index is calculated according to the following equation [6]:

$$I = \frac{R}{20} + \frac{(27 - T)}{10} \quad (5)$$

where, R = relative humidity (%), T = air temperature (^{o}C)

And the risk level is stated in Table 4.

Table 1 KBDI fire potential scale.

KBDI range	Forest fire potential
0-149	Fire potential is minimal
150-299	Fire behaviour is predictable
300-499	Fire behaviour is somewhat predictable
500-699	Fire suppression is a significant undertaking
700-800	Fire behaviour is mostly predictable

Table 2 Nesterov fire potential scale.

Nesterov range	Forest fire potential
0-300	Fire potential is minimal
301-1,000	Fire behaviour is predictable
1,001-4,000	Fire behaviour is somewhat predictable
4,001-10,000	Fire suppression is a significant undertaking
> 10,000	Fire behaviour is mostly predictable

Table 3 *k* values in function of rainfall quantities.

R (mm)	0	0.1-0.9	1.0-.2.9	3.0-5.9	6.0-14.9	15.0-19.0	>19
k	1	0.8	0.6	0.4	0.2	0.1	0

Table 4 Angstrom fire potential scale.

Angstrom range	Forest fire potential
> 4.0	Fire occurrence unlikely
3.0-4.0	Fire occurrence unfavourable
2.5-2.9	Fire conditions favourable
2.0-2.4	Fire conditions more favourable
< 2.0	Fire occurrence very likely

3.5 Index5: Modified Keetch-Byram Drought Index

The modified Keetch-Byram was recently posed and verified in Greece.

$$DF = \frac{(200 - Mod\ KBDI_{t-1})(1.713e^{(0.0875T+1.5552)} - 14.59)}{1+10.88e^{-0.001736R}} \cdot 10^{-3} \quad (6)$$

And if we set the *R* threshold equal to 3 mm, the final equation of the modified KB drought index takes the form:

$$Mod\ KBDI_t = Mod\ KBDI_{t-1} + DF - (R-3) \quad (7)$$

$Mod\ KBDI_t = Mod\ KBDI_{t-1} + DF - (R-3)$ (if there is any rainfall $R > 3$ mm); *T*: Temperature (^oC), [6].

3.6 Index6: FMI

The fuel moisture index, *FMI* is a simple, intuitive way to assess fuel moisture content. It is calculated using measurements of dry-bulb temperature and relative humidity.

$$FMI = 10 - 0.25(T - R) \quad (8)$$

where *T*: Air temperature (℃); *R*: Relative humidity (%)

FMI is a dimensionless index and should not be considered as giving a direct estimate of fuel moisture content, but the lowest it is, the greatest the risk of fire occurrence is Ref. [8].

3.7 Index7: FWI

The forest fire weather index FWI is an estimation of the risk of wildfire based on a Canadian empirical model developed and widely used since 1976. It uses four meteorological parameters: noon relative humidity; noon temperature; precipitations during 24 h and the maximum speed of the average wind. It computes many functions and indices (wind function f(W), fine fuel moisture function f(F), duff moisture function f(D), initial spread index R and build-up index U) to conclude the final form S of the index [9]. The risk level is found in Table 5.

$$ln(S) = 2.72[0.434 \ln(0.1Rf(D))]^{0.647} \text{ if } 0.1Rf(D) > 1$$
$$S = 0.1Rf(D) \text{ if } 0.1Rf(D) \leq 1 \quad (9)$$

4. Experiments and Results

Upon collecting weather data of 2012 and forest fire resides for the same period, we applied the above mentioned indices. We used among the ranges of risk the threshold that gives the best performance for each index, and the decision is taken accordingly. Hereunder in Table 6 are the thresholds that suit to be best estimating high risk of fire occurrence.

To compare the results obtained upon indices implication, single ROC plot analysis is utilized. Single threshold examination that is supported by accuracy is used instead of multiple threshold ROC analysis. As in this study, our concern is to figure out the applicability of each of the seven indices in Lebanon and regions of the Mediterranean sharing identical climate. We are not seeking to find the most optimal threshold for each index. In our case, it was easy to identify the most relevant decision threshold applied on a relatively small data base benefiting from the maximum efficiency of each index [10]. In order to reach our goal and plot ROC graph that will estimate the accuracy of each of the indices, special values are computed: TP (true positive), FP (false positive), TN (true negative) and FN (False Negative) as in Table 7.

TP means that the index predicted the occurrence of

Table 5 FWI fire potential scale.

FWI range	Forest fire potential
0-1.0	Fire occurrence very low
1.1-4.0	Fire occurrence unlikely
4.1-8.0	Fire occurrence unfavourable
8.1-16.0	Fire conditions favourable
16.1-29.0	Fire conditions more favourable
> 29.0	Fire occurrence very likely

Table 6 Selection of efficient decision threshold for indices.

Index	"High Risk" Threshold
Nesterov	> 4,000
Modified Nesterov	> 5,000
KBDI	>= 300
Modified KBDI	>= 60
Angstrom	< 3
FMI	< 14
Canadian FWI	>= 15

Table 7 ROC required values computed in North Lebanon for 2012.

	TP	FP	TN	FN
Nesterov	24	139	196	2
Modified Nesterov	24	129	206	2
KBDI	16	125	210	10
Modified KBDI	21	151	184	5
Angstrom	19	35	300	7
FMI	6	3	332	20
Canadian FWI	25	93	242	1

fire where fire actually occurred while FP indicates that the index expected there was a fire where no fire actually ignited. Similarly, TN means that the index declared that there wasn't a fire incident, and it was right in its decision while FN means that the index claimed no fire happened where effectively fire had occurred. In 2012, Lebanon recorded 26 forest fire incidents in its north. As clearly shown in Table 7, *FMI* had the greatest number of TN but the least number of TP whose greatest value was achieved by the Canadian index.

To get the scientific indications drawn by these values, other two values are to be derived. These values are TPR and FPR that stand for True Positive Rate and False Positive Rate, respectively [10].

$$TPR = TP/(TP + FN) \quad (10)$$

$$FPR = FP/(FP + TN) \quad (11)$$

The *TPR* defines how many correct "FIRE" predictions occur among all fire incidents available during the test. *FPR*, on the other hand, defines how many incorrect "FIRE" predictions occur among all "NO FIRE" days available during the test (Table 8).

Now, *ROC* plot can be displayed showing the trade-off between *TPR* and *FPR*.

Plots of the seven results above in the ROC space are given in Fig. 2 The diagonal line divides the ROC space. All the indices represent good classification results as they are above the diagonal. The result of FWI clearly shows the best predictive power among all applied indices as it is the nearest to the upper left corner of the plot. Angstrom follows FWI although it has a lower FPR, but FWI surpassed it by the highest TPR.

Other measure could be done, it is the accuracy rate (ACC) that is computed (Table 8) using the following Eq. (11):

$$ACC = (TP + TN)/(TP + FP + TN + FN) \quad (12)$$

As it is clear from the formula, ACC is dependent on both true "FIRE" predictions (TP) and true "NO FIRE" predictions (TN) equally. This is a big trouble in our case study. As we can see from Table 8, FMI got an accuracy rate of 93.6% which is trivially giving a wrong evaluation. This high percentage is attributed to being scoring the lowest FPR.

Precision and *Recall* can be more accurate as they depend on TP only as illustrated in their equations [11]:

$$Precision = TP/(TP + FP) \quad (13)$$

$$Recall = TP/(TP + FN) \quad (14)$$

Recall is another term for TPR. It can be seen that *Recall* gave an accurate evaluation of the most applicable index as it depends on TP and FN, the two most interesting values in the field of Forest Fire Prediction.

Another measure could settle the issue. It is the Area under the Curve or AUC, calculated using the following Eqs. (10) and (11):

Table 8 TPR, FPR, ACC, AUC, precision and recall measures—North Lebanon 2012.

	TPR	FPR	ACC	AUC	Precision	Recall
Nesterov	0.923	0.415	0.609	0.754	0.147	0.923
Modified Nesterov	0.923	0.385	0.637	0.769	0.157	0.923
KBDI	0.615	0.373	0.626	0.621	0.113	0.615
Modified KBDI	0.808	0.451	0.568	0.678	0.122	0.808
Angstrom	0.731	0.104	0.884	0.813	0.352	0.731
FMI	0.231	0.009	0.936	0.611	0.667	0.231
Canadian FWI	0.962	0.278	0.740	0.842	0.212	0.962

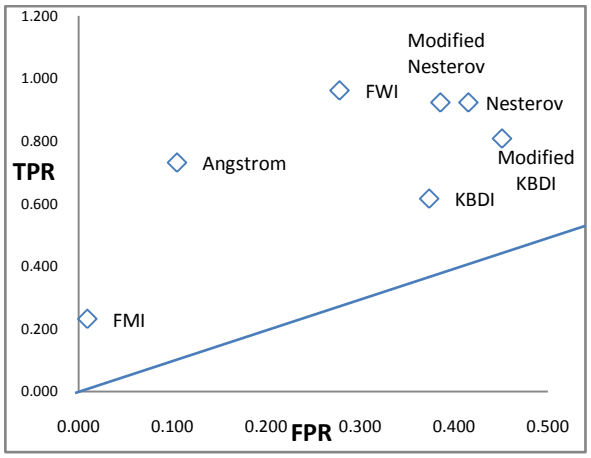

Fig. 2 ROC space and plots of the seven prediction indices.

$$AUC = (TPR - FPR + 1)/2 \quad (15)$$

The reliable and valid AUC estimate can be interpreted as the probability that the classifier will assign a higher score to a randomly chosen positive example than to a randomly chosen negative example. The latter is strongly requested in our case study.

Here as shown in Fig. 2, it is clearly deducted that *FWI* is the most applicable index in Lebanon with an AUC of 84.2% and angstrom comes in the second place with an AUC of 81.3%. Conversely, FMI is the most irrelevant index for Lebanon and the Mediterranean with an AUC of 61.1%.

5. Conclusions

In this paper, seven commonly used fire detection indices all over the world are applied on Lebanese data to identify the index that best fits Lebanese and Mediterranean climate. These indices are Angstrom, Nesterov, Modified Nesterov, KBDI, Modified KBDI, FMI and the Canadian FWI. ROC plot and measures are used to analyse the indices performance in the studied area; we see that the best fitting model is the FWI.

Many measures could be done for evaluation: Accuracy, Precision, Recall, Area under the Curve and others. But these should not be used without a clear understanding of the studied field and corresponding identification of chance or base case levels of the study. Using these measures, a system that performs worse in one of the measures, can appear to perform better under any of other commonly used measures.

In the field of forest fire prediction, TP and FN tend to be the most important parameters that would affect dramatically on the index decision, while FP and TN are less important. Human beings lives, their properties and the environment are much more valuable than the costs could be paid for precautions and actions in case of false alarms. Thus in our case study, AUC is found to be the most accurate measurement for a précised evaluation.

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Journal of Communication and Computer 11 (2013) 1410-1421

A Survey of Virtual Worlds Exploring the Various Types and Theories behind Them

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Received: October 11, 2013 / Accepted: November 10, 2013 / Published: November 30, 2013.

Abstract: Virtual Worlds are computer-simulated environments, depicting an experience where many people interact simultaneously within the same three-dimensional environment by means of customizable avatars. They have been around since the beginning of computing, and give a sense of a real world where people may communicate, socialize and play games. Virtual Worlds are part of social computing, which are critical implementations for not only gaming, but also for business, education, and online social networking. This paper surveys the field of Virtual Worlds. It describes the different types of Virtual Worlds such as social Virtual Worlds, casual, role playing, branded, e-commerce and e-government. It also goes into the theory and the ideas and goals which have been explored, and some detail of the laws effecting Virtual Worlds, the variations, their issues and their problems. The findings are discussed together with their current situation and how they appear to be developing and their uses.

Key words: Virtual Worlds, virtual environments, social interaction, educational tools, social tools, business tools.

1. Introduction

1.1 Goals

This paper surveys the current state of Virtual Worlds. It describes the different types and their different uses, and the issues and problems that come with them. This survey paper does not present any new results based on research, though combines a number of existing information.

1.2 Definitions

I will start with a short introduction and explanation to the definitions related to the subject which are made use throughout this paper. It is important to remember, that the paper assumes the reader has already some knowledge on the subject, therefore I will not explain the definitions with great detail.

1.2.1 What is a World?

"A world is an environment that its inhabitants regard as being self-contained" [1]. It is an enclosure with various attributes; the everything of an individual or society's knowledge or point of view, including philosophy, postulates, themes, values, emotions and ethics [2].

A world is an environment that is interpreted by human beings as an interconnected collection of places[3].

1.2.2 What does the Term "Virtual" Stand for?

Virtual refers to computer-simulated environments [4]. It is a computer mediated reality, presenting the user with an experience "which can be reasoned about as if it is a world, but the representation of that world is not to be analog to a possible physical alternative" [3].

Real is "that which is", imaginary is "that which isn't", and virtual is that which isn't while "having the form or effect of that which is" [1].

1.2.3 So Together, What does "Virtual World" Mean?

Computer simulated environments are called Virtual Worlds. They are inhabited by users in the form of

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"customisable avatars (graphical representations)" [5]. Each user in the virtual world can interact with the textual or graphical environment and other users [5]. "Virtual Worlds are places where the imaginary meets the real" [5]. They are unreal, "artificial, fictitious, imaginary, intangible and invented" [6].

Virtual Worlds can also be hybrids, meaning that they can be populated by both humans and agents, and can be used in a variety of domains [7]. They have six main features-shared space, graphical user interface, immediacy, persistence, socialization/community.

"A synchronous, persistent network of people, represented as avatars, facilitated by networked computers [8]."

1.3 Why is Virtual Reality an Interesting Topic?

Virtual Reality is an interesting topic because it works on bringing reality into the virtual. Its core functions are to duplicate the physics in the real world, and bring them into the virtual world—the core functioning of the computer—with a finite amount of resources. The creator of Second Life (a social virtual world), Philip Rosedale says that "both Virtual Worlds and the future of our own world as it becomes increasingly virtual" [9], and that in Virtual Worlds, we don't need to create and design objects using atoms "which do not contain any metadata" [9], but "if you got to redesign the world all over again, you might attach metadata to the atoms" [9]—in Virtual Worlds "we're about to have this power, to recreate the world in our own design" [9].

1.4 Paper Organisation

The paper is organized as follows: Section 2 goes into some details about how Virtual Worlds give the feeling of a real world, explaining their background, their laws, and also explains the use of avatars; Section 3 explains the different types of Virtual Worlds. Section 4 then contains the issued and problems which these environments face; and Section 5 discussing the findings and conclusions of this paper.

2. Going into Detail

2.1 Synchronous? Persistent? Network?

To give the feeling of a real world, it is necessary that all actions and events in the virtual world appear real-time and not turn based or non-real time-causing everything to be delayed. Giving the impression of a common-time will help for players (users) to create multi-user activities and other social activities. Like a real world, a virtual world cannot be paused. It must "continue to exist and function after the participant had left" [8]. This feature of persistence is what separates these worlds from other games such as Super Mario, Pac-Man, Tetris. The further into the past we go, we may also note how these online environments have evolved, from very unrealistic 2D interfaces, to realistic 3D interfaces with real-looking terrains such as grass, soil, sky and the sun. It helps to maintain an evolving and dynamic community and economy, existing without the participant's presence.

Although existing without the participant's presence, Virtual Worlds are still dependent on these users, as they are a network of people—an ecosystem, "in which the actions of a participant ripple through the world affecting every other part of the system" [8].

2.3 Background of Virtual Worlds

The use of Virtual Worlds has been increasing rapidly, and two of the most used applications of Virtual Worlds are MMORPGs and open-ended Virtual Worlds. In MMORPGs, a large number of players come together "and spend considerable amounts of time in order to engage in collaborative tasks or simply to engage in social interactions" [10]. In open-ended Virtual Worlds, users perform different types of tasks paralleling and augmenting daily life and work.

MMORPGs attract a large number of players, each of the players with different goals in mind. "Virtual Worlds can accommodate a very diverse user base" [10]—They provide users with both a system of

technological structure and a system of social structure. Virtual Worlds offer an environment where it is easier to "study the effects of collaboration on the way casual users move through ecologies of participation" [10], with the users alternating from being passive consumers and to being active contributors.

Open-ended Virtual Worlds gives the users an opportunity to change between observer and designer roles, while keeping a higher entry barrier for becoming a designer. Results found by B. Koehne et al. point "to a priority for socio-technical contexts that allow users to develop their roles based on social interactions through collaborative activities with other users" [10]. Users which are more experienced have a tendency of developing their own strategies, while the rest of the users seek guidance. "Meta-design theory can benefit designers of Virtual Worlds [10]." Meta-designers seek tools which help to give more freedom and power to the end-users to help them meet their needs. The advantage of these most of these tools is that "they do not discriminate between novice users and users with design experience in different domains" [10]—but create an even, flat entry level for all users [10]. In Table 1, one can see two types of Virtual Worlds, and a few of their features.

"Meta-design has emerged as a theoretical framework by supporting open systems that allow end-users to become designers in dynamic use contexts [10]." Most Virtual Worlds implement elements of meta-design in different ways. Examples of this are between Lord of The Rings Online and Second Life [10].

Virtual Worlds are built on real-world physics, they are concerned with "implementing the obvious" [1]. The physics in Virtual Worlds aim to give the feeling that the user is in an actual world and not some made surreal area. They must aim to be transparent, meaning that "players don't have to suspend any disbelief, because their senses pass the information right by without comment" [1].

All the issues which the real world address, should be addressed also by Virtual Worlds. The problem though for this to be accomplished is that Virtual Worlds have a limited amount of resources, so cannot compute all possible real-world physics. What Virtual Worlds can do more than real worlds are commands concerned with communication and ultraphysics [1].

2.4 Virtual World Laws

Virtual Worlds are "precursors to online communities" [5]. Therefore, since people can go to these Virtual Worlds and socialize with family, friends, and even strangers, laws need to be put into place. These laws can be developed by studying other Virtual

Table 1 Extending the Meta-design Theory: Engaging Participants as Active Contributors in Virtual Worlds—Benjamin Koehne, David Redmiles and Gerhard Fischer. Donald Bren School of Information and Computer Sciences, University of California at Irvine.

Meta-Design Concept	LOTRO	Second Life
convivial tools	Adventure & leveling system	prim design tools
domain orientation	goals from fixed set in the fantasy world context	user-imagined goals, open-endedness
open, evolvable systems	limited customization	unrestricted customization
underdesigned systems	fixed fantasy world context	minimalist environment
collaborative work practices	high cooperation amongst players	limited cooperation, specialization

Worlds, gaining insights on how these laws actually emerge just by having large numbers of people coming together online. More reasons why laws in Virtual Worlds are necessary is because payments are actually charged from non-virtual credit cards, and non-virtual banks, and in fact exchange rates are already put into place between virtual and real world currencies.

Virtual Worlds can act as an experiment in law-making, "and provide a serious challenge for real life legal systems" [5].

The current focus is regarding who owns the property created in Virtual Worlds, "what rights to privacy should users expect, how operators should work with real-world law enforcement" [11]. Also whether the virtual currency should be regulated and "whether or not real world laws should govern behaviour in Virtual Worlds [11]".

2.5 Why were Virtual Worlds Researched and Developed?

Virtual Worlds are "immersive 3D environments that enable large numbers of users to interact with one another over the internet" [12]. They began as computer games mainly due to the fact that they cost large sums of money to be created and developed; "computer games remain at the cutting edge of virtual world development" [12].

There are various reasons which encouraged different companies to develop a wide range of Virtual Worlds. Many companies develop and research Virtual Worlds for profits, to promote their products, to provide a platform for other businesses to make profits, to encourage users to collaborate. Other reasons also include research, and as a testing environment.

Philip Rosedale, the founder of one of the most well-known Virtual Worlds, Second Life, says that his motivation for Second Life, was his background in physics, and his interest in "chaos, chaos systems, nonlinearity and emergent behaviour" [13].

"SL [Second Life] is one of those weird kind of phenomena where every new piece of growth has been aperiodic and discontinuous but if you look at the growth. It has been a perfect curve and it is organic and exponential because it is a network effect business.... So what we don't want is little silos of marketing—nobody is interested in that" [13].

2.6 Avatars

"Avatars are currently a central part of digital environments because they define how the users can act and express themselves" [14]. Their use is increasing greatly in various types of applications—online games, icons, mailing systems, chat rooms, online communities and web forums.

Avatars are a presentation of a user, usually graphical 2D or 3D, through which the user interacts with the environment; they are the embodiment of the user—meaning "a controllable avatar in virtual space, an icon or a textual description" [14]. Many Virtual Worlds have their own avatar creation process and system as it is a critical part of the process of entering/signing up for a virtual world. While creating an avatar, the user can not only alter most of the features and criteria of the avatar (eyes, nose, lips, facial structure, ears, strength, fatness..) but also can alter the avatar's profession, likes and dislikes, expectations and behaviour. "Design decisions that may seem small can have huge influence on how the users can express themselves [14]."

It should be noted though that "avatars are not authentic descriptions of identity" [14]. They can be used to represent the reputation, or status of a user, even the user's emotional state. "The emotes, animations, gestures, voice, and speech style can be also considered as part of the avatar" [14]. Additional items to be placed onto the avatar (clothes, accessories, more elaborate body features) can be bought with real currencies [14].

"I like to connect to people in the virtual world, exchanging thoughts and ideas, when in the physical world we might never have the opportunity to cross paths."—Demi Moore [15].

3. Variations

3.1 Different Types of Virtual Worlds

A common view on Virtual Worlds is that they are "3D multiplayer games or chat rooms". Although they are mainly split up into two main categories—game-based worlds and social worlds, they can also be used as powerful education and business tools, and be split up into other various types, including:

- Social Virtual Worlds: "Social networking and Virtual Worlds have taken the internet by storm and some of the most popular and used applications today" (Papp, 2010). Social networking and Virtual Worlds are very similar since both of them encourage user interaction and communication. Social Virtual Worlds offer users real time interaction and communication [16]. Continued in 3.1.1.
- Casual Virtual Worlds: Casual Virtual Worlds are very similar to social Virtual Worlds. The main difference is that these Virtual Worlds focus on the user playing small games within the virtual world itself [5].
- Role playing Virtual Worlds: "When an actor acts, they take the role of a character" [17], while acting that character, the actor starts to understand the character. The more you act the character, you reach a point where you can no longer learn from it. "This leads to a paradox: as a role-player, you try to become your character, but if you succeed then you're no longer playing" [17]. Continued on in 3.1.2.
- Virtual Worlds for content creation: "The role of the game provider is to build tools with which users collaborate to tell a story" [18]. Virtual Worlds provide the tools to create not only clothes, but also 3D models to be included in their environment, accessories, and textures [18]. Continued 3.1.3.
- Educational Virtual Worlds/e-learning: "E-learning is a means of education that incorporates self-motivation, communication, efficiency, and technology". Education in Virtual Worlds encourages users [19] to communicate together, advance their technical skills, and gives them the means to educate themselves together with other students when they're away from the classroom [19]. Continued in 3.1.4.
- Interest focused Virtual Worlds: These Virtual Worlds focus on a specific real-world interest [5]. Continued in 3.1.5.
- Branded Virtual Worlds: These Virtual Worlds focus on a particular real-world brand, usually created and developed by the company developing the brand [5]. Continued in 3.1.6.
- Mirrorworlds: Mirror Virtual Worlds represent the real world—replications of the real-world. They help offer "wide scope for social interactions, collaborations and innovations" [20]. Continued in 3.1.7.
- Virtual Worlds platforms [5]: Virtual world platforms are frameworks which provide an easy way for users to create their own Virtual Worlds. "Some platforms even enable users to host Virtual Worlds on their own servers" [5].
- E-commerce: "Trade in Virtual Worlds is essentially a more sophisticated version of e-commerce" [21]. Virtual Worlds provide a better way of shopping online, as the user can visit a virtual store and view the product in 3D form, and not just a simple image. "Virtual Worlds have to potential to be the new infrastructure providers for B2C and, particularly, C2C" [21].
- E-government: Governments are always trying to connect more with people by forming online communities with various purposes in Virtual Worlds [22]. Continued in 3.1.8.

This study will now delve deeper into a detailed description of most types of virtual world mentioned in the above list. They will be dealt with in the order listed above.

3.1.1 Social Virtual Worlds/Casual Virtual Worlds

"Social Virtual Worlds have a blatantly commercial feel [23]". Many users of Virtual Worlds manage business ventures that generate virtual and/or real income. They are many times referred to as online

shopping malls, where both online and offline goods are promoted. Many business ventures and promotional campaigns for real life products and services are hosted by social Virtual Worlds. They are "increasingly serving as arenas for the promotion of offline political and social agendas" [23]. Social Virtual Worlds are also used by users to express themselves in less tolerant geographical areas [23].

Many social Virtual Worlds exist. Examples of these worlds are Active Worlds, Blue Mars, Club Cooee, Empire of Sports, Free Realms, Frenzoo, Friends Hangout. IMVU, is a relatively new 3D Virtual World which had been founded in 2004. Its main focus is chatting and socializing with new people in their world, while accessorizing your avatar, buying new 3D "rooms" where you can hang out. It also provides a way for users to express themselves by designing their own clothes, furniture and rooms, and selling them in the virtual world, and allowing the user to post their designs in their catalog [24].

Social Virtual Worlds "focus on enabling conversation among users and are often compared to 3D chat rooms. They often include virtual goods that users can buy, and some enable users to create and customize their own virtual rooms or spaces" [5].

Avatars in social worlds are very important. "Many events and activities in social worlds revolve specifically around avatars, in the form of avatar customization classes, clothing sales, costume contests, modeling contests, and fashion shows" [23]. The creation of the avatar "engages users in the process of online identity formation and they must decide how closely they want their virtual bodies to resemble their offline bodies" [23].

3.1.2 Role Playing Virtual Worlds

"Students will understand 'the greater picture' and the possible roles that the many groups played" [25]—role playing in Virtual Worlds allows the users/players to become someone else, something else. They may experiment playing the role of a construction worker, architect, businessman, salesman or any other job they wish. They can even be a housewife, cleaning up the house! "...allow students to explore what might have happened if other variables had existed" [25].

Role playing Virtual Worlds are also known as MMORPGs (Massively multiplayer online role-playing games). They "encourage players to assume a role in a themes world and progress through the game by competing with or against other players in a variety of quests in the fictional environment" [5]. Examples of such games are World of Warcraft, Age of Canon, EVE online and Gaia Online [5]. MMORPGs have become big business since users/players are required to pay a monthly subscription. "To be successful, game publishers must characterize their player population so that they can provision sufficient resources to support the game [26]."

3.1.3 Virtual Worlds for Content Creation

"One of the main challenges of using virtual environments is the high cost of creating content [27]." There is a wide range of modelling tools available, though they all someway or another, require some type of training and have a steep learning curve [27]. Virtual Worlds are promoting and making it easier for users to create their own content. They are built upon the power of users, and as described previously, Virtual Worlds are a persistent network of people, powered by the people. This makes it important for users to be able to help the world their practically "*living in*" to evolve, and be part of it.

To start off with, Virtual Worlds have all implemented some type of tool to create and modify the user's own avatar. Allowing the user not only to change the appearance, but also facial expressions, facial and body features and other characteristics from eye color to likes and dislike—the power of modifying avatars have already been explained in Section 2.4. Other tools are available also to import content such as furniture. Virtual Worlds not only enable users to create content, but also sell them to other users. User-generated content increases greatly the different uses for Virtual Worlds [5]. An example of this would

be to create a virtual classroom where teachers may teach their students, and create the content for the virtual world if for example they cannot afford it, or don't have access to the needed material.

"Design and Decorate Your Space—Create the experience you've always wanted"

"Make and Sell Your Own Designs—Share your creativity! Create your own 2D and 3D designs, and sell them.." [24].

3.1.4 Educational Virtual Worlds/E-learning

"Aim to educate their users about a certain topic. Most often these worlds are targeted at children and offer similar features as the casual gaming Virtual Worlds" [5]. Technology is rapidly advancing, especially in Virtual Worlds. This also affects the educational landscape. "Impacting educators, students and researchers [28]". Teachers in schools are using computer games as "learning environments with a focus on education over entertainment" [28].

Computer games are addicting, engaging, and have many stimulating aspects. "It has been demonstrated that games can improve skills in areas such as communication, problem-solving, and numeric tasks [28]". Although they have so many positive aspects, there are problems with making use of them in schools. Many educators are only willing to introduce educational computer games if they are made compulsory in the curriculum.

With relation to Virtual Worlds, one particular virtual world which focuses most on education is Whyville, which targets youths known as "tweens"—and has nearly seven million users. In this virtual world, users create avatars and "explore, interact and play...earning money in a virtual currency"[28]. The world also enables the users to communicate with each other by chatting, participating in forums and attending "Greek theatres"—special interest gatherings [28].

"Educationalists need to embrace the idea that environment and interaction are inseparable."—Simon Bignell

3.1.5 Interest Focused Virtual Worlds

The name reveals it all. Interest focused Virtual Worlds are those which main target is a specified interest/topic. They are "...focused around users' real world interests, such as sports, fashion, music, etc.." [5].

3.1.6 Branded Virtual Worlds

Many companies seek to increase their target market and expand their advertising campaigns by creating their own private Virtual Worlds which make use of the products they are trying to sell. They are created "around a certain real life brand and can include elements of other types of Virtual Worlds" [5]. Some of these Virtual Worlds, require the user/player to purchase a real world product to access the virtual world [5].

3.1.7 Mirror Worlds

There exists Virtual Worlds which are built and designed to actually mimic/mirror the actual real world. "Mirror worlds are quite literally worlds or 3D visualisations that mirror the physical world [20]." There are many known mirror Virtual Worlds, the most famous one being Google Earth. "Mirror worlds can be embedded into other unrelated applications [20]." With regards to education and training, these types of Virtual Worlds can introduce very interesting options [20].

Mirror worlds make use of "sophisticated virtual mapping, modelling and annotation tools, geospatial, sensor technologies and location-aware and life logging technologies" [20]. "They can be used as 3D maps or to promote tourism [5]."

3.1.8 E-Government

Very few governments have actually made use of Virtual Worlds. The United States is one of those few. The US government in the virtual world is split into three areas—the hall of states, the innovate building, NICs virtual corporate headquarters—with an interface to real time data. It also has several meeting spaces, training facilities, and orientation area for new users [29].

Some ideas were mentioned during Philip Rosedale's talk—experimenting with new governments and see how it works, and when will Virtual Worlds bring an impressive enough experience for interface devices. Rosedale explains how in the case of Second Life, it feels "kind of markety, felt kind of capitalist… and that was by intent" [29]. He also explains how the current user base is not large enough to enable experiments such as experimental government forms to show good results. Regarding the second idea regarding interface devices, Rosedale goes into detail how although there are devices which work quite well with interesting technologies, they still have areas were to improve, he goes on saying that with the improvement of these devices, it will enhance the user's experience in Virtual Worlds, allowing the user to show facial expressions, bandwidth, posture and gestures [29].

3.2 What does Each Type Have In Common?

Some Virtual Worlds which are freely available for download were visited:

- Social virtual world—There and IMVU
- Role playing virtual world—World of Warcraft
- Virtual world for content creation - Second Life
- Educational virtual world—Whyville
- Mirror virtual world—Twinity

All the Virtual Worlds in question, all from different types, are mostly based on the way the community is built. They all provide some sort of chat room/s where the users can communicate, and express themselves. Some of the Virtual Worlds also allow the user to change the mood on his/her avatar, even make body gestures.

All the Virtual Worlds, except for most of the educational worlds, emphasize on shopping, accessorizing your avatar, being creative by creating your own content. Most of them also emphasize on actually flirting and showing off with other avatars.

3.3 What are their main differences?

The main differences between the Virtual Worlds were mainly how they are marketed and promoted. Graphics on most of them are slightly different, some more realistic than others, but all of them need improvement on this aspect. Some of the Virtual Worlds, such as second life, provide more freedom especially with user created content, providing most of the code of the whole system free on their wiki, together with a tutorial for their scripting languages and tools. Twinity although doesn't provide the user with the source code, has a better designed and explained wiki and tutorials for the user to create his/her own content and textures. Other Virtual Worlds, such as IMVU, have their own tools in the world itself —more like templates—and the user is only allowed to customize those.

"Yet comparatively, Virtual Worlds would seem to provide a much more social and creative form of media engagement than the regular and passive consumption of television programming that is the staple of many American media diets [30]."

4. Issues and problems

4.1 What are the Problems That Virtual Worlds Face?

4.1.1 Issues in Education with Virtual Worlds

Virtual Worlds require robust hardware and a relatively fast broadband internet connection with a large download limit. This causes problems as many schools and classes do not provide or do not meet these requirements. Also "Virtual Worlds do not work with screen readers, limiting their accessibility to the visually impaired [31]."

Virtual Worlds are vast and enable the user to do practically anything he wants, although this will enhance the learning experience, it will also distract the student. It will also create problems with students who are less technical and are less interested in computers, making it even more difficult for them to get a grasp of what's happening and to keep up with the more technical, and maybe more experienced students.

"Cost is another issue [31]". In Virtual Worlds, although many of them provide a free subscription

together with other paid plans, to create a permanent area which would be used for the activities involved, a premium subscription needs to be bought at a monthly cost [32].

4.1.2 Resource Problems

A problem which has been described by Philip Rosedale in his talk at Singularity University is that due to the limited amount of computer resources, it cannot be guaranteed that the state of things in the virtual world will remain the same until it is moved by some type of "*force*" or by another avatar. He explains it by using a short example—if you leave a ball in a cup, due to the limited amount of resources, the virtual world cannot guarantee that if you leave it there for a while, it will remain there. He goes on to explain the problem with an engineering term called "tunneling" [9].

4.1.3 Issues

The most interesting issues that revolve around Virtual Worlds are caused by the way people have to pay to buy items—not real items, but virtual. "If you take something from someone else in a virtual world, is it theft? How can you control your brands in a virtual *world?* [32]". Another question which arises is if a user creates his own items for himself, what are his proprietary rights, and who owns the rights—the user or the owners of the virtual world [32]?

Virtual Worlds such as Second Life are facing the problem of not being intuitive, in such a way that even technical users find it difficult to actually make use of the world—even for basic functions such as removing a pair of shoes. Virtual Worlds costs a lot of money to be developed and maintained, and the problem is that they're still remaining quite empty. Second life is facing problems far greater than this, and far greater than any problem which other Virtual Worlds are facing. "Governments are scrutinizing the four-year-old site as a possible haven for tax-free commerce, child-porn distribution and other unsavory activity" [24], and also "European governments are upset that adult avatars are having sex with childlike ones" [24].

The success of Virtual Worlds depends on the performance of the users. "Of equal importance is ensuring the health and welfare of users who interact with these environments [33]". If during the development of the Virtual Worlds the aspect of human interaction and health is ignored, it "could result in discomfort, harm or even injury [33]". Therefore, it is important that any advances in the technology of Virtual Worlds do not come "at the cost of human well being". The main effects of Virtual Worlds on humans, are psychological, and also on the eyes—"which will be closely coupled to HMDs or other visual displays" [33] and can easily be harmed.

Problems that can be caused by Virtual Worlds are seizures caused by flickering lights, phobic effect (claustrophobia) and anxiety. Many more issues and problems can affect humans, though these are mainly in a special type of virtual world where displays are used close up to the eyes (usually in the form of glasses), where the user feels as if he himself is in the world.

Virtual Worlds and environments may negatively affect a user's social life in the real world. The increase of usage of these technologies will result in the user participating in events, and socializing with people more in the virtual world than in the real. Harming more the eyes, and in many cases increasing the potential for back injuries and repeated strain injuries.

Other questions with regards to issues caused by Virtual Worlds are: "Will individuals transfer violent virtual experiences to the real world?" [33], "will people turn their backs on the real world and become 'contented zombies' wondering around synthetic worlds which fulfill their whims but disregard their growth as a human being?" [33], and will "users experience traumatic physical or psychological consequences due to a virtual interaction? [33]" I have also encountered another question, which made me think and relate to friends which I know make use of Virtual Worlds, mainly MMORPGs—"Will people

avoid reality and real social encounters with peers and become addicted to escapism? [33]"

4.1.4 Working Online

A common question is whether work can actually be performed online. "Several organizations have set up a shop in Second Life" allowing users to buy products and services using the virtual currency [21].

Gary Anthes wrote an article from the point of view of someone looking for a tool for e-collaboration and for e-business. He starts off by explaining that he found problems on actually using a virtual world and getting used to it. He writes that after getting used to the world, he visited some "virtual island owned by IBM" [34], and says that when he tried out some functions, not all worked and warns "Advice to vendors: If you are going to play this game, make sure it works" [34].

"The main conclusion that one can infer from that article is that Second Life is still far from reaching the point at which it will serve as an effective e-collaboration tool for organizations" [21].

4.2 Have Virtual Worlds Provided any Help in the Real World?

Virtual Worlds help users from around the real world to actually meet, share ideas and discuss their opinions and views. They provide a meeting point for all types of users and communities. One of the communities which formed in a virtual world, was actually a group of scientific thinkers. The community organized some events, their first one being the first Citizen Cyberscience summit, which was hosted in London—with "around 100 professional and amateur scientists from around the world" [35]. The summit's aim was to examine "progress in and the potential of internet-based citizen-science" [35]. Their examination resulted that progress so far was great, "including the discovery of new space objects and protein structures" [35], together with "the potential to provide free computing power to scientists in poor parts of the world" [35].

"It gives scientists access to computing power and potentially assistance in helping them analyze data that they could never afford otherwise [35]."

5. Conclusions

Virtual Worlds are rapidly advancing and although are lacking in their number of users, big companies are investing in them and even developing their own branded Virtual Worlds. Their advantage is when having a considerable amount of users, they can be used as a test case for implementations in the real world. They can help provide statistics, and research analyses for many cases, such as product research and marketing techniques.

The current situation of virtual worlds is quite disappointing. Many of them take a long time to load content, and don't really quite capture the essence of the user's personality and looks, especially due to their very low graphic quality [24]. The use of virtual world applications is increasing and improving in many different areas such as business and health training, though some problems are arising. There is a need for common standards "and the validation of assessment and evaluation techniques" [20].

Virtual Worlds have been existent for over years, but their true potential has only been recognized around 5 years ago. This leads to the need of monitoring "what the exact implications will be of virtual self-organized communities" [20] to make sure that they reach their full potential and create a "cohesive community that works together for the greater good" [20].

With regards to laws, a number of laws should be set up and standardized throughout all the Virtual Worlds. Content in these worlds are bought with real money which is exchanged to the virtual currency. Also any transfer of data between users should be monitored to prevent the exchange of real world illegal content [24].

Questions arise regarding Virtual Worlds, such as: why should people use Virtual Worlds within education? An answer to this would be that Virtual Worlds allow users to "interact in a manner mimicking real-life interactions" [36]. Each virtual world has its

own user base, with "hundreds of thousands of registered avatars". Each avatar is used for different roles such as gaming, social networking, marketing and commerce, and "the most potential" [36] role is technology-enhanced learning education. Virtual Worlds have the advantage by providing a "heightened sense of community to students when they are away from University premises" [36]. Virtual Worlds acts as "a good forum for students to come together, despite physical location, to reflect on educational material at their own pace [36]." Although Virtual Worlds has some stronger points than VLEs they need to work together, and not be better than VLEs, "for it to be successful as a vehicle for learning" [36].

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Journal of Communication and Computer 11 (2013) 1422-1432

Energy Efficient and Dynamic Hierarchical Clustering for Wireless Sensor Networks

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Received: October30, 2013 / Accepted: November 15, 2013 / Published: November 30, 2013.

Abstract: This paper presents an innovative dynamic hierarchical clustering protocol for wireless sensor networks. In networks that mainly apply multi-hop communications, the huge amount energy consumed by relay tasks of nodes near the sink node causes premature network death, so the lifetime of these nodes needs to be improved efficiently in order to prolong the duration of network service. The aim of the proposed dynamic hierarchical clustering protocol is to minimize the difference of energy dissipation of these nodes and to adjust the size of clusters dynamically in the neighborhood near the sink node. Furthermore, the proposed protocol reduces transmission delay. The energy efficiency of the proposed algorithm is verified through simulation.

Key words: Energy efficient; wireless sensor networks; dynamic cluster size; TDMA; multi-hop.

1. Introduction

The micro-power wireless sensor approach to autonomous environmental monitoring has been gaining much interest recently [1, 2]. It is an emerging technology that benefits from the ongoing developments of sensor techniques, low energy consumption electronics and low-power radio frequency design [3]. Compared with expensive sensors, the growing demands of reliable and inexpensive sensors have led to a new type of wireless sensor applications. Though such sensors cannot compete with expensive sensors in terms of accuracy, they are still popular because of high availability and accessibility.

The performance of a wireless sensor network can be accessed from the perspective of QoS (quality of service). Two critical aspects significantly impact QoS of wireless sensor networks. Firstly, it is clear that QoS depends on the reliability of sensor data. But, there is a tradeoff between data reliability/accuracy and system expense from a practical point of view. For certain applications, such as forest fire tracking and battle field monitoring, sensor nodes are generally accepted to have a one-time deployment in those scenarios. As a result, practicality demands the use of inexpensive sensors. Secondly, maximum network lifetime is a significant goal of wireless sensor networks. It indicates a need for both high energy efficiency utilization and equal energy dissipation distribution. The quality and reliability of sensor readings decreases dramatically if nodes in the network prematurely cease to function due to rapid energy depletion. Furthermore, the death of critical nodes may result in major network partitioning and disconnection. Therefore, extending the lifetime of a WSN has attracted much interest in the research field of energy consumption and load distribution [4-6].

Since wireless sensor networks are usually deployed in environments where grid-power is not available, the consumption of energy becomes the most important issue in order to maximize network lifetime. Some energy efficiency oriented algorithms have been proposed to minimize energy consumption of each

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sensor node in the network. Energy consumption control is studied from two aspects, which are sensor and transmission. From the sensor perspective, a sensor should only consume energy when it is needed to execute tasks and for transmission/reception over the air. In other words, the ideal condition of a sensor implies minimized idle status. Ye et al. [7] proposed S-MAC protocol to reduce unnecessary energy consumption by putting nodes into sleep mode when not working. However, this scheme results in delay when one node is trying to communicate with another node while it is in sleep mode, called sleep delay. Dam et al. [8] present a T-MAC protocol to further reduce unnecessary energy consumption. When two nodes are communicating, all neighbor nodes and their surrounding nodes enter sleep mode. Nevertheless, the sleep delay problem is still exhibited here, and it even may be potentially worse than S-MAC, since more nodes are in sleep mode at the same time, which means higher possibility of sleep delay.

From the viewpoint of transmission mode, in order to further improve energy efficiency, the multi-hop transmission technique is applied in wireless sensor networks, due to its lower energy cost than single-hop transmission. Kim et al. [9] proposed a cross layer design (ECLP) and energy oriented listening window schedule to minimize energy consumption. However, such transmission mode raises a new type of problem, since any wireless sensor network that has one sink and applies multi-hop transmission faces the same problem called "hot spot"; this is the problem whereby the nodes near the sink node, especially those which can communicate with the sink node with one hop, may consume much more energy (i.e., more data relay operations, called one-hop nodes) than nodes that are farther away. This problem exists in many WSN routing protocols such as ECLP and T-MAC. Common sense dictates that the energy consumption distribution must be optimized. Unequal distribution may result in critical disconnections, which means major connection failure (i.e., alive nodes cannot reach the sink node) in the wireless sensor network. Heinzelman et al. [3] proposed LEACH (low-energy adaptive clustering hierarchy); it was intended to relieve this problem by combining clustering technique and single-hop transmission. Li et al. [10] proposed an EEUC (energy-efficient unequal clustering) mechanism. This algorithm was designed to relieve energy cost pressure of nodes near the sink node by assigning distinct size of clusters. Both EEUC and LEACH integrate multi-hop and single-hop transmission, which is seen as one of promising solutions for unequal energy cost distribution.

This paper proposes a dynamic hierarchical clustering approach that is designed to distribute energy consumption of nodes near the sink node as equal as possible, and to reduce the likelihood of critical disconnection. Moreover, the proposed protocol aims to balance quality of service and energy consumption. This paper's contributions are: (1) a minimization of the difference of energy dissipation of nodes near hot spots; (2) balance single-hop and multi-hop transmission modes, (3) adjust the cluster size dynamically according to node population, and (4) energy load sharing mechanism are introduced.

The remaining parts of this paper are organized as follows. The next section describes an innovative dynamic hierarchical clustering design and a few important elements. This is followed by a detailed description of different network stages in Section III. The simulation and analysis results are given in Section IV. Finally the conclusions and recommendations for future works are given.

2. Dynamic Hierarchical Clustering

Starting from the sink node, the proposed algorithm forms hierarchical layers of clusters of nodes. Each cluster is assigned a distinct level ID, which represents the cluster-hop count between sink node and the particular cluster. Notice that the level ID is assigned in a monotonically increasing fashion since the hop count increases along with the expanding size of entire

wireless sensor work. Member nodes of a cluster are assigned the same level ID as the cluster in which they belong. During the data communications stage, cluster heads from higher layer clusters relay data to lower layer cluster heads until the messages are received by the sink, which is located at the lowest layer cluster. To ensure cluster quality, cluster size is able to adjust to a certain extent according to particular situation, which is explained in details later in this paper. In order to improve transmission efficiency, the transmission scheme is a combination of multi-hop and single-hop routing.

In this paper, the network has similar configuration as widely used wireless sensor networks. There are V stationary nodes in the wireless sensor network:

$$V = N \cup S \quad (1)$$

The N is the number of sensor nodes, and S is the number of sink nodes. They are randomly distributed in the target field. To simplify the simulations, we assume one sink node, but many potential source nodes are contained in the network. Each sensor node is able to determine its approximate relative distance from other nodes by analyzing received signal strength. All nodes have the same capability and initial energy. Each node has two communications radios to allow either multi-hop or single-hop message passing, but, the single-hop option is the default mode. The transmission distance of multi-hop mode can be varied at a certain range to compensate unequal density of nodes due to random distribution. The lower bound of this range is set as default multi-hop transmission distance. Details are described in the next subsection.

The motivation and overview of dynamic hierarchical clustering algorithm is presented in this section. In order to clearly describe the cluster formation and data transmission schemes, the essential synchronization packets are also introduced ahead of the description of the proposed algorithm.

The core idea of this dynamic hierarchical clustering design is to generate an energy efficient and dynamic hierarchical cluster topology for the network. This approach is motivated by the "hot spot" problem, which is faced by many other routing protocols. It is an inevitable situation for such network configuration. Nevertheless, its disadvantages cannot be omitted and satisfactory performance can be achieved through optimization. The approach used to relieve this problem is to minimize energy consumption difference among cluster heads in each layer; especially those near the sink nodes (one-hop nodes), which take-on most of the burden of this problem. This approach automatically serves to prolong network lifetime. Furthermore, the proposed algorithm also intends to reduce general transmission delay, which includes sleep delay and hop delay.

In order to simplify the description, the clusters which have level ID of n are referred to as Level n clusters. In the network, each node can hold at most two level IDs, which are CM_Ln and CH_L(n+1). The CM_Ln means the node is a cluster member of the Level n cluster, and CH_L(n+1) means the node is the cluster head of the Level n+1 cluster.

As described above, nodes closer to the sink node are more likely to consume more energy during service. This condition also applies to clusters near the sink node. Cluster heads dissipate energy with higher rate than cluster members, due to their responsibility of managing and gathering data from cluster members. Furthermore, cluster heads near the sink node bear more relay tasks than those far away from the sink node. Therefore, a dynamic hierarchical clustering technique is introduced to vary the cluster size according to different situations. Since the clusters near the sink consume more energy than those farther away for the sink, this paper creates smaller cluster sizes near the sink to allow a greater degree of load balancing opportunity, and creates larger cluster sizes for remote clusters to save on unnecessary energy dissipation.

The proposed routing protocol consists of dynamic hierarchical clusters that mainly perform multi-hop data communications. However, such links can be terminated whenever a relay node on the link breaks

down. To reduce data loss and improve network robustness against disconnection, this paper presents two options when such situation appears. One way is to choose an alternative transmission link, which may be considered as a fast recovery solution. Another way is to transmit data directly to the sink node with single-hop transmission mode. Though the former solution may cost more delay than single-hop, it is the preferred option since it requires less energy consumption.

In wireless sensor networks, the energy consumption for different transmission schemes is calculated as [1]:

$$\mathrm{E}_{Tx}(l,d)=\begin{cases} lE_{elec}+l\varepsilon_{fs}d^2, & d<d_0 \\ lE_{elec}+l\varepsilon_{mp}d^4, & d\geq d_0 \end{cases} \quad (2a)$$

$$E_{Rx}(l)=lE_{elec} \quad (2b)$$

The E_{elec} is the electronics energy dissipation and it is determined by related operations during service (e.g., modulation/demodulation, filtering and coding/decoding). The energy consumption of transmit amplifier $\epsilon_{fs}d^2$ and $\epsilon_{mp}d^4$ are exclusively chosen according to the distance threshold d_0. From previous work [1, 3], the difference of amplifier energy dissipation is considerable. Therefore, a proper value of d_0 is important for wireless sensor network design.

During the network clustering stage, four packets, SYNC, $\mathrm{SYNC_{chd}}$ and $\mathrm{SYNC_{cfm}}$ and $\mathrm{SYNC_{reply}}$ are utilized. These four packets are similar to SYNC packet in S-MAC [9] and ECLP [7]. The proposed protocol uses the SYNC packet for cluster formation, management and synchronization; the $\mathrm{SYNC_{reply}}$ is used for leaf node confirmation operations. The $\mathrm{SYNC_{chd}}$ and $\mathrm{SYNC_{cfm}}$ packets are only used when cluster members try to get permission from their cluster head to be next level cluster heads. Elements of $\mathrm{SYNC_{chd}}$ are similar to SYNC packet. $\mathrm{SYNC_{cfm}}$ packet contains *c_id* and *c_chd_confirmed* indicates that request is confirmed. Details are described in the next section.

Elements of the SYNC packet include network routing information. The*c_id* indicates the packet sender, and *c_lv* is the level of cluster created by the sender (i.e., *CH_Ln*). Value of -1 means this SYNC packet is a pure cluster joining confirmation packet. The *c_parent* points out the parent node of sender. Since the transmission range is variable, *c_range* stands for this cluster head's current transmission range. The *c_cost* is calculated on the basis of the sender's energy situation. It is written as,

$$SYNC_{c\_cost\_i}=\frac{E_{T\_i}}{E_{R\_i}} \quad (3a)$$

$$E_T=E_{Tx}+E_{Rx} \quad (3b)$$

The E_R is the sender's residual energy, and E_T is the average energy cost for one round relay task. Furthermore, a $\mathrm{SYNC_{reply}}$ packet contains two items, which are *c_lv_max* and *node_total*. The *c_lv_max* is the maximum or deepest level of cluster that exists along one branch. The *node_total* is the total number of nodes along this branch. Both values are updated by each cluster head that relays this $\mathrm{SYNC_{reply}}$ packet to the sink node.

Another essential component for each sensor node is the node management table. The table mainly includes elements that indicate the relation between this sensor node and its neighbor nodes.

3. Algorithm Description

This section discusses the proposed protocol. First, a workflow description of the protocol over the entire wireless sensor network is given. This is followed by a description of the two stages of the algorithm, which are network clustering stage and data communications stage.

At the beginning of the network clustering stage, an initialization process is executed. Each node will broadcast its information with randomly short delay whenever it starts working. Nodes that receive the message calculate relative distance and store information in their node management table. If a new node joins the network during service, it will also broadcast its node information, and surrounding nodes

then broadcast their node information to the new node. The sink node is able to broadcast to all nodes in the network. In this case, initially, each node has a node management table that stores information of surrounding nodes and the sink node.

In the network clustering stage, the dynamic hierarchical layering starts from the lowest level cluster; *Level 0* cluster is first created and cluster head is the sink node with level ID of 0 (*CH_L0*). Each member in the *Level 0* cluster has a level ID:*CM_L0*. Each *CM_L0* node is able to create, one degree higher, *Level 1* cluster. By this, each *CM_L0* can also have another ID of *Level 1* cluster head (*CH_L1*). In practice, whether a *CM_Ln* becomes a cluster head (i.e., *CH_L(n+1)*) depends on several criteria; a full description is given in the next subsection. The reason of such network design is that interference and cluster overlap should be minimized in the network. Since each node is able to calculate approximate distance with another node, it is better to only let cluster members near geometrical boundary of a cluster create higher level clusters. The formation of hierarchical clusters grows like a tree. Starting from the *Level 0* cluster (i.e., *CH_L0* is the sink node), potentially several branches to the next higher level clusters are created. The next level clusters, in turn, create branches to next higher level clusters. This continues until no other higher level clusters can be created.

The cluster quality is assessed by ratio of cluster head and cluster member. According to previous work[3], the energy efficiency can be maximized at a certain interval of ratio. In practice, this interval should be adjusted based on specific wireless sensor network condition. Moreover, the density of nodes decreases along with increasing wireless sensor network size, such produce a situation that a cluster head (e.g., *CH_Ln*) does not have sufficient cluster members that can be next level cluster heads (i.e., *CH_L(n+1)*). In this case, the proposed protocol is able to allow the cluster head to enlarge the cluster size in order to have more cluster members that can be next level cluster heads.

In the data communications stage, TDMA (time division multiple access) technique is applied for intra-cluster communications. The time schedule is denoted by*TS_Ln*, where *n* represents the level of cluster. Cluster head with level ID of *CH_L(n+1)* collects data from its cluster members using *TS_L(n+1)*, and then relays data to *CH_Ln* during time slot *TS_Ln*. The inter-cluster TDMA slot is subdivide into *m* sub-slots for interference-free cluster member communications. By this approach, signal interference is minimized and sleep delay is substantially reduced.

The sink node marks itself as *Level 0* cluster head (*CH_L0*), and updates the *c_cost*and*c_lv*= 0 into the SYNC packet. The sink node then sends the SYNC packet to its one-hop neighbors using the multi-hop transmission mode. The one-hop neighbors which receive the SYNC packet choose the sink node as their cluster head, and then they store the value of *c_id*, *c_lv*, *c_range* and *c_cost* into their node management table. In this case, the one-hop neighbors of the sink node become cluster members of the *Level 0* cluster (*CM_L0*). According to the assumption of network configuration, only one sink node means there is only one *Level 0* cluster in the network. Therefore, layer 0 is comprised of only one cluster. The cluster members of *Level 0* then individually decide whether they should be the ones to create the next level cluster.

To maintain cluster quality, a certain percentage of next level cluster head should be considered [3]. After the sink node broadcasts a SYNC packet, pure cluster members broadcast SYNC packets to confirm joining and all potential next level cluster heads broadcast $SYNC_{chd}$. The sink node analyzes the received SYNC and $SYNC_{chd}$ packets; it will add node *i* into its cluster member list if node *I* indicates the sink node is its parent node. The sink node then knows the ratio of potential next level cluster heads and total cluster members. If it meets the quality requirement, then the sink node broadcasts $SYNC_{cfm}$to issue permission. Otherwise, the sink node increases its multi-hop

transmission range by updating *c_range* (i.e., cluster size), and starts from broadcasting SYNC packet again.

If the quality requirement is still not met when the maximum multi-hop transmission range is reached, $SYNC_{cfm}$ is issued anyway because the best effort is made. Once potential next level cluster heads receive $SYNC_{cfm}$, they update and broadcast SYNC packet to establish their own clusters. In simulation, the maximum multi-hop transmission distance is 60% longer than the default setting. Above scheme can be summarized as below:

Step 1: CH_L0 sends SYNC packet and then listens for incoming packets;

Step 2: *CH_L0* receives SYNC and $SYNC_{chd}$ packet, and analyzes the cluster quality. It goes to Step 3 if the requirement is met; otherwise it goes to Step 4;

Step 3: *CH_L0* issues $SYNC_{cfm}$ and *Level 0* cluster is formed;

Step 4: *CH_L0* increases cluster size and goes back to Step 1. If maximum multi-hop transmission range is reached, it goes to Step 3 instead.

At the *Level 1* construction stage, node *i* is designed to set up its own cluster via SYNC packet. In general, whether a node with level ID of *CM_Ln* should create another level ID of *CH_L(n+1)* depends on the distance between itself and its cluster head *CH_Ln*, called boundary distance. An equation of boundary distance given to determine the eligible nodes is given by (Eqs. (4a) and (4b)):

$$P\_CH\_L(n+1) = \begin{cases} 0.9, & bd < \dfrac{d(CH\_Ln, node\_i)}{c\_range} < 1 \\ 0, & otherwise \end{cases} \quad (4a)$$

$$bd = \min(max_{bd}, min_{bd} * \rho * (n+1)) \quad (4a)$$

The *P_CH_L(n+1)* is the possibility of a *CM_Ln*to be a *CH_L(n+1)*. *c_range* is the multi-hop transmission range of the cluster head, which is included in the SYNC packet.$d(CH_Ln, node_i)$is the approximate distance between node *i* and its cluster head, it is calculated by node *i* and stored in the node management table during initialization process. The *bd* is the boundary distance threshold that distinguishes possible cluster heads of next level from pure cluster members. The *n* is the level of current cluster. To improve energy utilization ratio, lower level clusters are designed to have more nodes that could be next level cluster heads by assigning looser distance restrictions. For instance, the boundary distance threshold allows more nodes with level ID of *CM_L0* to become a potential cluster head than nodes with higher level ID. Furthermore, tighter boundary distance restriction is applied to reduce redundancy of higher level clusters. A parameter ρ is used to adjust the boundary distance. The reason for doing this is because the nodes that are farther away for the sink have a smaller chance of suffering from the "hot spot" problem. Accordingly, mitigation of the "hot spot' problem is decreasingly required for load balancing for cluster layers located further away for the sink. Nevertheless, cluster quality is always ensured or strived through dynamic transmission range.

If node *i* meets distance requirement, it then sends $SYNC_{chd}$ to ask for permit, once it gets $SYNC_{cfm}$from its cluster head, node *i* is able to set up its own cluster via SYNC packet. Node *i* just sends SYNC packet to its cluster head to confirm joining if it does not meet the distance requirement. By this approach, a wireless sensor network is formed through well controlled and organized clusters.

As shown in Fig. 1, all cluster heads (denoted with solid circles) except the sink node are also cluster members of lower level clusters. The solid triangles represent pure cluster members.

Similar with the sink node, after receiving $SYNC_{cfm}$ packet from sink node, node *i* first calculates *c_cost* and upgrades *c_lv* by one, thus, indicating it is the cluster head of *Level 1* cluster (*CH_L1*). *c_parent* is assigned with ID of the sink node, *c_range* is set to the default multi-hop transmission range. Node I updates these values and broadcast SYNC packet to its neighbors. A Node *j* receives set up a contention timer

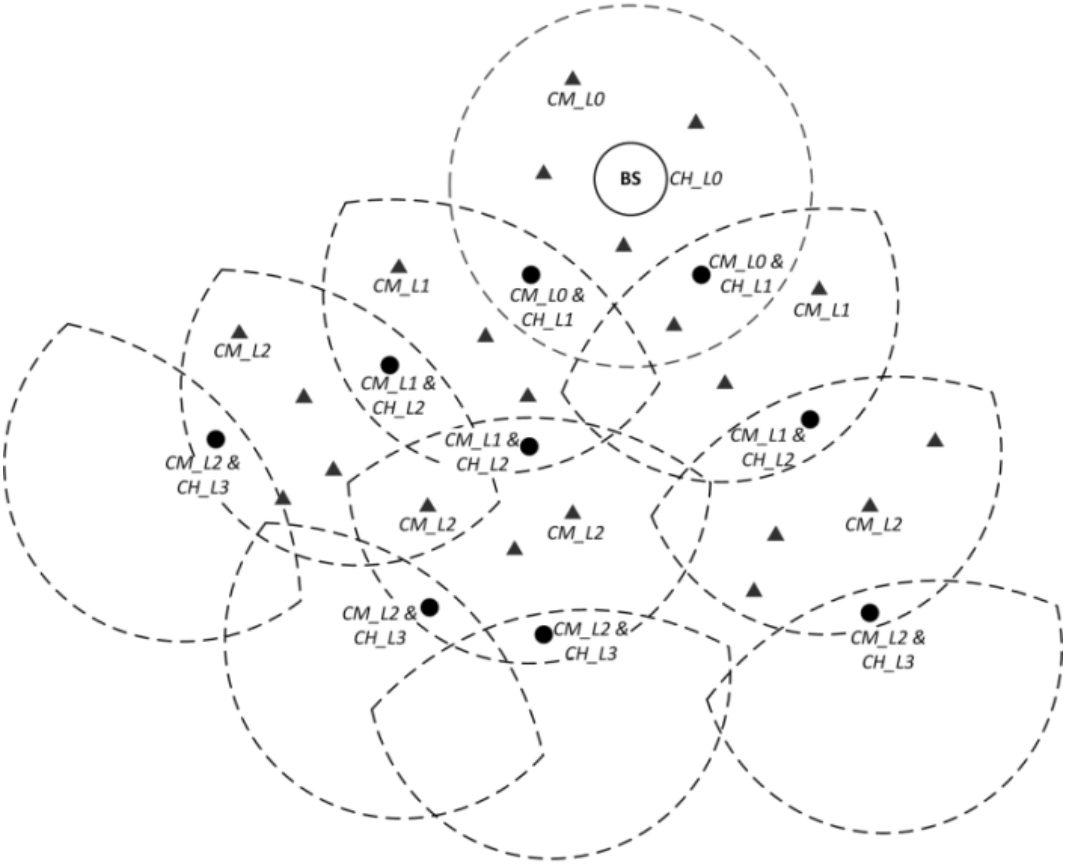

Fig. 1 Network clustering stage.

as soon as it receives a SYNC packet. *j* chooses the SYNC packet sender that has lowest value of *c_lv* as its cluster head after the timer is out. *c_cost* is the second comparison variable if more than one SYNC packets have the same value of *c_lv*. The node that has the second lowest value of *c_cost*is also stored as an alternative parent. The value of *c_lv* in the SYNC packet determines which level of cluster that node *j* becomes a cluster member of. For instance, the node *j* becomes cluster member of *Level 1* cluster (*CM_L1*) if it chooses node *i* as the cluster head. In this way, each node is a cluster member of lower level cluster and possibly to be a cluster head of higher level cluster. This procedure is executed until the leaf nodes are encountered.

If a cluster head does not hear SYNC packet that indicates this node as a parent node, it then marks itself as a leaf cluster head and transmits a $SYNC_{reply}$ packet along the formed branch. Data of *c_lv_max* and *node_total* is updated. *c_lv_max* is the level of this leaf cluster head, and *node_total* is the sum of direct and indirect child node, obviously, the value is 0 for a leaf cluster head. The $SYNC_{reply}$ packet is then relayed by each cluster head all the way to sink node. Each cluster head then updates the value of *node_total* of first received $SYNC_{reply}$ packet by adding the number of its direct child nodes. The cluster head then compares *c_lv_max* with its up to date highest level information. Cluster head updates its own highest level information if *c_lv_max* is larger, otherwise *c_lv_max* is updated. As a result, all cluster heads are able to know the highest cluster levels of this branch, and the amount of direct and indirect child nodes. Therefore, cluster heads have a sense of logical position in the network and relay load. This is for the purpose of load threshold function, which is stated in the data communications stage. When all $SYNC_{reply}$ packets reach sink node, the network clustering stage is formally finished and

switch to data communications stage.

TDMA is applied for intra-cluster communications during the data communications stage for the purpose of interference avoidance. Sensory data is relayed through cluster heads at each layer and then received by the sink. A cluster head has two energy thresholds, one is called base threshold and another is load threshold. The load threshold reflects relay load degree of a cluster head and base threshold represents the percentage of energy that a cluster can allocate for data relay tasks. Since nodes in the wireless sensor network are randomly distributed, there is no doubt the energy consumption among cluster heads is not even. Especially for those have a large amount of direct and indirect child nodes or are close to sink node are likely to dissipate much more energy. To reduce likelihood of major network disconnection, cluster heads with less relay load should share relay tasks with those are overloaded. If load threshold of a cluster head is breached, it broadcast a message to all cluster members so that any cluster member that has alternative parent should ask to join an alternative cluster. In the meanwhile, both the cluster head and alternative cluster heads recalculate load threshold. The load threshold is calculated as,

$$c\_load\_thresh = max\_thresh * (1 - \alpha \frac{n\_child * c\_lv}{node\_total * c\_lv\_max}) \quad (5)$$

The*max_thresh* is the maximum load threshold a cluster head can have. The*n_child*is the number of direct child nodes and *c_lv* is the level of this cluster head. Parameter α is chosen with proper value to adjust results. A load threshold helps overloaded cluster heads reduce unnecessary relay tasks. However, whenever the base threshold is violated, the cluster head stops relay service and only sends its own sensory data. To ensure quality of service, nodes that lost links switch cluster heads if they have alternative parent nodes. Otherwise, they automatically switch radio to single-hop transmission mode until next network clustering stage.

4. Simulation and Results

The simulation of the proposed DHCP (dynamic hierarchical clustering protocol) was implemented in Matlab. Three comparison algorithms were demonstrated using the same parameters with dynamic hierarchical clusters design. The network performance is evaluated through system survival period, link quality, and energy consumption. Parameters used in the simulation [3] are given in 0. Base threshold is set to 10% of maximum energy capacity. Maximum load threshold of cluster head is 30% of maximum energy capacity. Minimum and maximum boundary threshold are 20% and 80% of transmission range of multi-hop mode. The default transmission range is 30m and the maximum is 50 m, which allows a cluster head to enlarge its cluster size by no more than 2 steps. Such configuration is verified through the first simulation which is shown in Fig. 2.

The first simulation is conducted regarding variable transmission distance. There is a trade-off between extra size and network lifetime. On the one hand, larger cluster size provides more potential next level cluster heads to ensure cluster quality. On the other hand, each cluster head then has to bear more data relay tasks, which result in higher energy consumption rate. The simulation illustrates how cluster size influences network lifetime and performance. The enlargement

Table 1 Simulation parameters.

Parameter	Value
Network coverage	(0,0)~(300,300) m
Base station location	(150,150)m
Number of nodes	675
Initial energy	0.5 J
BASE_R	30 m
STEP_R	10 m
MAX_R	50 m
E_{elec}	50nJ/bit
E_{fs}	10 pJ/bit/m^2
E_{mp}	0.0013 pJ/bit/m^4
E_{DA}	5 nJ/bit/signal
Data packet size	4,000 bits
ρ	2

steps start from 0 and go to 5. We focus on one-hop node efficiency, as shown in Fig. 2, which presents the percentage of working one-hop nodes at different maximum steps setting when they begin to drop due to low energy. As can be seen, the network lifetime is optimized when the maximum steps are 2.

The second simulation was conducted to evaluate network lifetime and quality of network linkage. Three comparison algorithms are the LEACH (low-energy adaptive clustering hierarchy), EEUC (energy-efficient unequal clustering) mechanism, and ECLP (enhanced cross-layer protocol). LEACH is selected since it is a typical clustering model for wireless sensor networks. Deep and systemic research has proved its value. The EEUC routing algorithm is designed to assign distinct cluster size to relieve energy pressure problems of nodes near sink node, which is also one of research goals of this paper. Furthermore, both LEACH and EEUC apply two radio transmission modes, which are the same as proposed by the present DHCP algorithm. Both ECLP and DHCP apply network layering design. The comparison of ECLP and DHCP would concentrate on energy dissipation of one-hop nodes.

As Fig. 3 illustrates the number of live nodes changes over time. DHCP demonstrates significant longer service period than LEACH and EEUC. However, the ECLP shows better performance.

The reason is analyzed from a node efficiency aspect, which is shown in Fig. 4. Curves of LEACH and EEUC in Fig. 4 are the same with Fig. 3 since the link of these two algorithms is guaranteed by single-hop transmission mode. However, the node efficiency (percentage of nodes that are able to reach the sink node) of ECLP drops faster than DHCP, which means ECLP network is malfunctioned earlier than DHCP. This is because that node in ECLP is link oriented, which means the sink node receives data from nodes closer to itself. This leads to huge energy consumption of these one-hop nodes, and obviously, the number of available one-hop nodes decrease during service. As a result, branches in the network tend to one-hop distance converge to one-hop nodes that are still available for data relay task. All nodes that have distance larger than

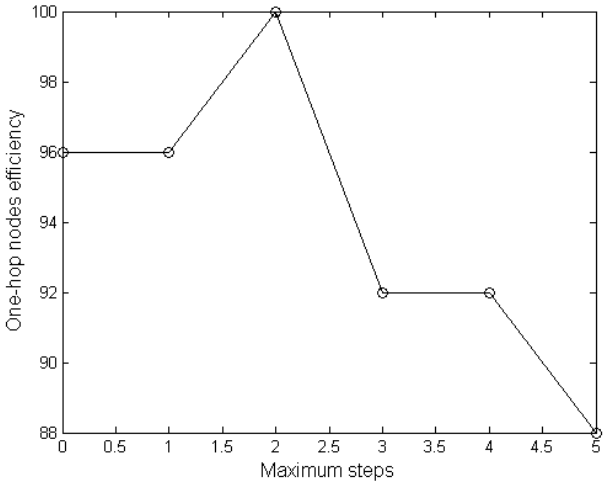

Fig. 2 One-hop nodes efficiency with different steps.

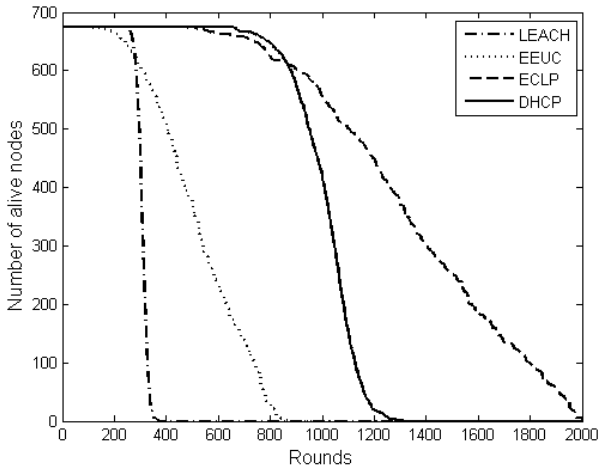

Fig. 3 Number of live nodes.

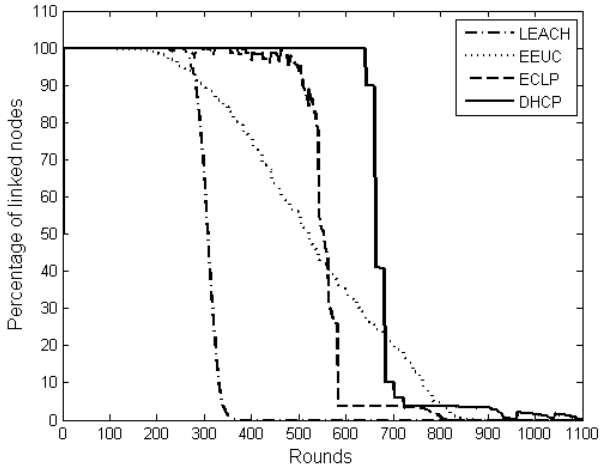

Fig. 4 Node efficiency.

lose links at the time the last one-hop node's residual energy is below its base threshold. Therefore, though some nodes are still alive in ECLP, the network cannot service any more. When compared with EEUC and LEACH, DHCP illustrates more stable network performance which guarantees more nodes alive and active during service.

The comparison between ECLP and DHCP mainly concentrates on node link quality, in other words, number of nodes that are hierarchical to the sink node during service. The variance of DHCP in Fig. 4 is much smaller than ECLP. It is because layers in ECLP categorize nodes, but layers in DHCP classify clusters. Moreover, ECLP routing protocol does not apply single-hop transmission, nodes lost link broadcast error message and when reconnection attempt fails, they stop relaying data until next network configuration stage. In DHCP, a node that lost link transmits data directly to the sink node. Furthermore, as shown in Fig. 3, the DHCP maintains high quality of service performance and then most nodes die in a short period of time, which implies good performance on balancing energy consumption for each layer.

A one-hop node efficiency comparison between ECLP and DHCP is illustrated in Fig. 5. The number of one-hop node is less than 10% of total number of nodes in the simulation. The percentage of available one-hop nodes decreases over time. Nevertheless, DHCP provides longer network service time in terms of percentage of available one-hop nodes. This is critical since one-hop nodes relay information for all other sensor nodes.

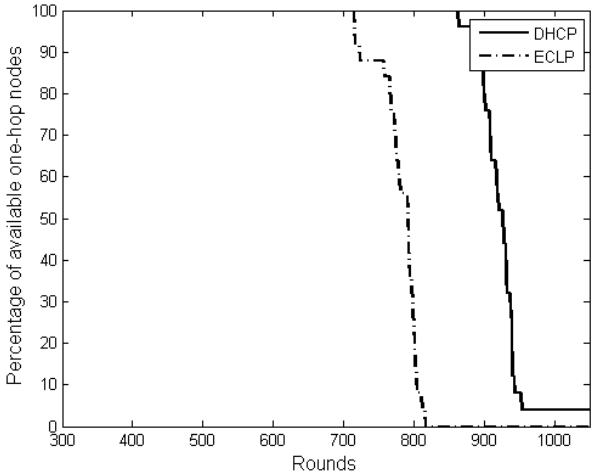

Fig. 5 Efficiency of one-hop nodes.

9. Conclusions

This paper presents an innovative routing approach for wireless sensor networks. The goal of this proposed algorithm is to minimize energy dissipation difference in each layer, especially to relieve energy consumption pressure of nodes near sink node. A variable multi-hop transmission range approach is proposed in order to maintain cluster quality. Furthermore, a novel utilization of single-hop transmission mode is described in order to maintain node efficiency in the network. The dynamic hierarchical cluster design demonstrates promising network performance through simulation. The network lifetime is significantly prolonged compared with other algorithms. By using TDMA communications protocol and layer network architecture, the transmission delay is also reduced. The future work is needed to continue improve node efficiency, and the algorithm should be enhanced in larger scale of wireless sensor networks.

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Journal of Communication and Computer 11 (2013) 1433-1439

Research on Time Slot Assignment Algorithm in Wireless Sensor Network Used in Meter Reading System

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Received: October 11, 2013 / Accepted: November 10, 2013 / Published: November 30, 2013.

Abstract: The wireless sensor network for automatic meter reading system has special features of not sensitive to power, fixed topology and delay tolerable. These features make the traditional MAC protocol mostly does not apply to the network. In this paper, a distributed time slot algorithm was put forward, considering the characteristics of automatic meter reading system and principle of a strong edge coloring problem. The algorithm could determine nodes own time slot with two hops and ensure conflict-free communication between nodes. At last, it did performance simulation and analysis for the time-slot assignment algorithm. Simulation results showed that the algorithm can assign the time slot quickly and accurately. Also it showed that the algorithm efficiency is mostly affected by the actual maximum number of nodes, and is little affected by the expansion of the network.

Key words: Wireless sensor network; automatic meter reading system; strong edge coloring problem; time slot assignment.

1. Introduction

AMR (automatic meter reading) refers to using technologies such as communication and computer network to read and deal with data automatically [1]. The development of automatic meter reading technologies not only can improve the energy consumption level of management needs, but also is the necessary requirement of the rapid development of network and computer technology. At present, the underlying communication means for automatic meter reading system, there are three main researching directions: power line carrier, RS485 bus and wireless network.

PLC (power-line carrier, power line carrier) is a communication method which uses power line as communication media for information transmission of voice or data [2, 3]. Its advantage is that using the power line transmission can save resources. But it has problems of electromagnetic interference and signal processing. The meter reading system based on RS485 bus mainly uses a 485 bus network to connect the acquisition terminals and concentrators completing data transmition and introduction, in which communication is stable and reliable. But in the actual application, laying special line is needed, which not only causes that construction is inconvenient, but also channels are easy to damage with difficult recovery and large amount of maintenance. Wireless sensor network technology is a kind of close distance, low complexity, low power consumption and low cost of two-way wireless communication technology [4, 5]. For the continuous improvement of power system monitoring and measurement requirements, automatic meter reading system based on wireless sensor network, fundamentally solves the uncertainty of network, communication situation ensuring the real-time meter for monitoring.

The wireless network used for automatic meter reading system is based on electric meter as the sensor

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Supported by "the Fundamental Research Funds for the Central Universities" (No.13MS86).

node, and has characteristics of a fixed topology, the little network change and high tolerance of message delay [6]. Therefore, on the initial stage of establishing networks, assigning fixed time slot for each node avoids a collision occurs when nodes transmitting at the same time.

In this paper, the difference between the wireless sensor network and traditional wireless network is analyzed firstly. At the same time, the network topology of automatic meter reading system is described. Finally, a time slot assignment algorithm is proposed on the basis of strong edge coloring algorithm [7, 8]. The simulation shows that the algorithm can assign time slot for all of the nodes in a relative short period of time and can make sure it's conflict-free.

2. Design of Meter Reading System

2.1 Particularity of Wireless Meter Reading System

The traditional wireless sensor network nodes are mostly deployed in harsh environments and sparsely populated region relying on battery power. As a result, energy consumption of nodes is an important factor to consider when the network is designed. However, nodes of wireless meter reading system use the cable power supply. So in the system design, energy requirements can be slightly reduced. In addition, a certain degree of data delay is acceptable in meter reading system.

2.2 Topology of Meter Reading System

The topology of wireless sensor network which this paper considered is from the meter reading terminal to the cells (i.e., in the living quarter). However, cell to the power meter reading center is not in the scope of the study. The topological structure is shown in Fig. 1.

The system contains cells, data acquisition terminals and electric energy meters using wireless communication between devices. The subdistrict has a small base station. And a data acquisition terminal which is responsible for the collection of all electric meter data in two floors of the building is deployed between each of the two floors in the living quarter. The features make the network topology form a natural cluster structure. The data acquisition terminal is the cluster head, and forms a sub cluster with its subordinate user meter. What's more, the ability of information processing and data transmission is good for the cluster head. When the collected meter data reach a certain threshold, the data will be transmitted to the data collection terminal through wireless one-hop way. When data acquisition terminal monitoring data, the measurement data will be received and together with the corresponding gauge user information packed together. Finally, this information is transmitted to the cells in a multi-hop way.

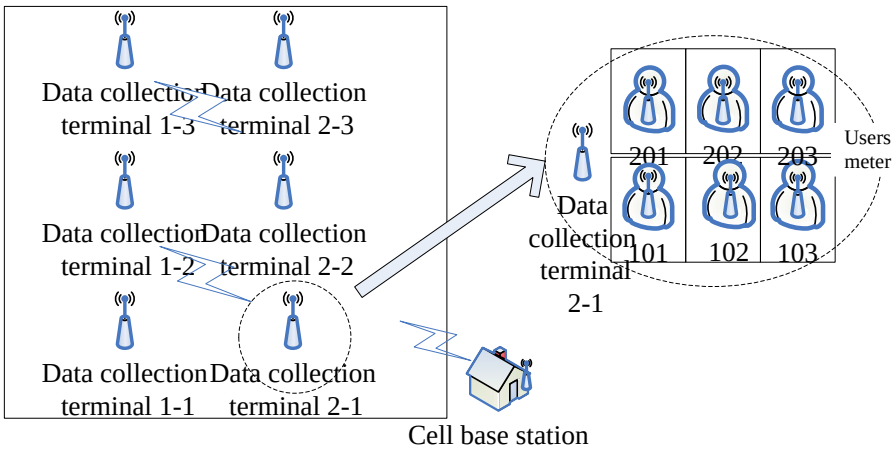

Fig. 1 The wireless sensor network for meter reading system.

3. Time Slot Assignment Algorithm

3.1 Principle of Algorithm

The two-hop wireless network time slot assignment was discussed in Ref. [9], by ensuring that the network connectivity graph adjacent edges had different colors, in order to achieve the chain of nodes having different time slots. Graph coloring was a coloring to each node of the graph with adjacent nodes having different colors and the total number of color as little as possible [10]. On this basis, the development of strong edge coloring problem of graph [11] referred to that the figure had a reasonable edge coloring, making edge coloring set of the connections between arbitrary two adjacent the two-hop wireless network time slot allocations in the graph different from each other. Time slot assignment problem has certain similarity with graph coloring problem, so node time slot assignment can be abstracted as graph vertex coloring problem. The undirected graph G = (V, E) is said wireless sensor network with V being a node set and E being edge set. There is edge e = (u, v) when and only when that u and v belong to V, and that u and v can communicate. The meter reading system network takes clusters as units, therefore, v represents the cluster that contains the cluster head and the ordinary nodes in the cluster. Moreover, the wireless sensor node communication mode is broadcast communication, in order to guarantee that the time slot conflict-free. The time slot assignment of node v and its two adjacent nodes are not the same.

3.2 Algorithm Design

A node has five states: UNSET1, UNSET2, REQUEST, GRANT and SET. Because the color distribution is conducted according to the cluster as the unit and each cluster belonging to the unbalanced network, so the cluster head nodes deal with most of the logic. If not specified, the node in the paper represents cluster head nodes of each bunch and it is unnecessary to go into details next. Fig. 2 is the entire state transition diagram of the algorithm.

The time slot assignment algorithm (color) is as follows: each node in advance selects a random integer from the [1, 4] as the initial color value color with the default wait time being T, and assume that nodes have acquired neighbor node information at the start.

When nodes start, all nodes will be into initial UNSET1 state. In UNSET1 state, a node first generates a random number R_1 of [0, 1]. If the random number is less than p_1 = 1/3, the random number is successful, then the node will be into UNSET2 state. On the other hand, the node A stays UNSET1 waiting for the next time T_A.

After node entering UNSET2, it will generate a new random number again. If this random number is less than p_2=1/k, A will get communication rights with neighbor node. Otherwise, A keeps UNSET2 condition. After waiting time T_A, it will generate a random number p_2 again. Through the information exchange, node A can decide their own color. The process of pseudo code is as follows.

```
while(true)
{
p1 = node.random();
if(p1 < 1/3)
{
while(true)
{
p2 = node.random();
if(p2 < (1/node.getMaxCj()))
{
call request function;
}
else
{
sleep(node.T);
break;
}
}
```

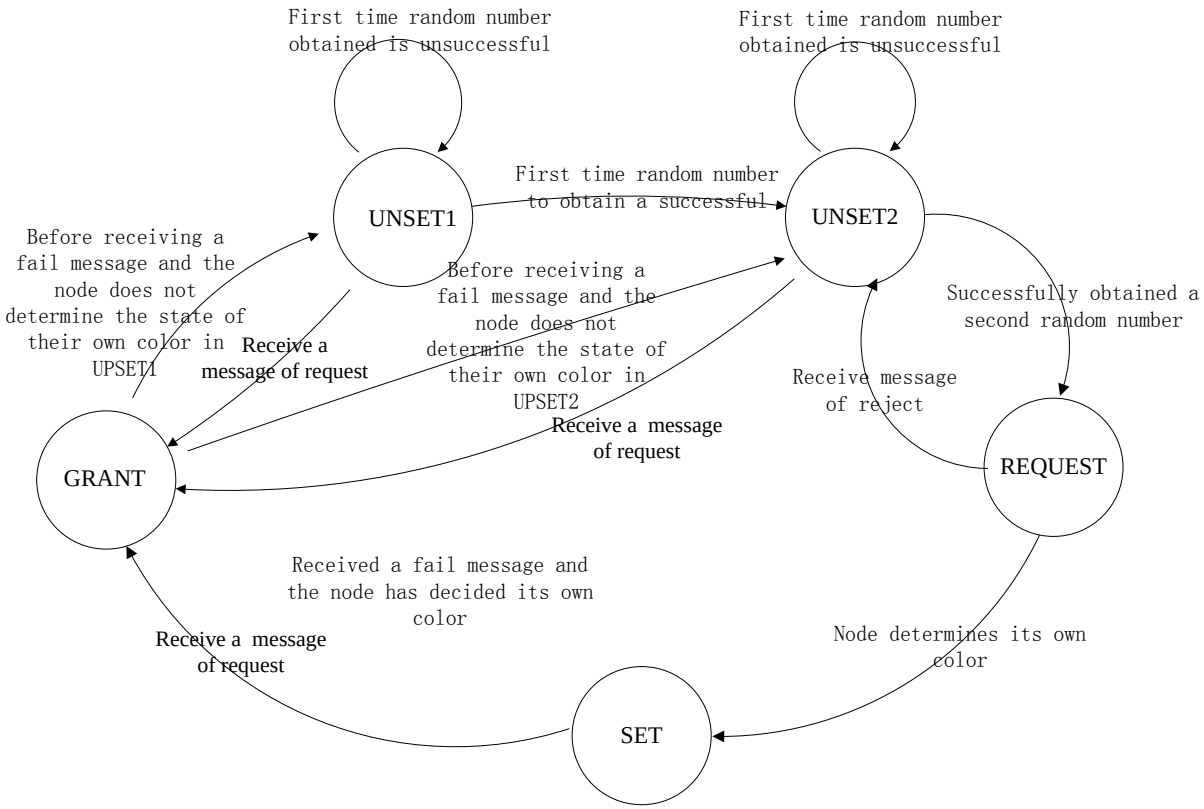

Fig. 2 The node state transition diagram.

```
}
else
{
sleep(node.T);
}
}
```

Correlation function description:

random(): Generate a random number of [0, 1]

getMaxCj(): Make Cj as the number of adjacent nodes with undetermined color in two-hop range, and the function returns the maximum value in the collection Cj of neighboring nodes within two-hop.

sleep(): Nodes just monitor the network and don't do any logical operation. If it has received the request from other nodes, the nodes will respond.

When the node A has generated a random number twice successfully and got communication rights, A will be into the state of REQUEST. At the same time, it will broadcast message $request_A$ to all neighbors. And If R_2 is bigger than p_2, node A keeps in state UNSET2 unchanged waiting for the next time T_A. T_A is set to $3d_A$ and d_A is the biggest rough estimation for one-way message delay.

When neighbor node B received the message $request_A$ from A, and B is in state UNSET1, UNSET2 or SET, B will convert to state GRANT. At the same time, B will send message $grant_B$ to A. In the message $grant_B$, color information selected by its one-hop neighbor nodes is contained.

While B received the message $request_A$ from A, and B is in state of REQUEST or GRANT, B will send message $reject_B$ to A. When received the message reject from any one node, A will broadcast $fail_A$ to all one-top neighbor nodes and turn state into UNSET1. When B obtained $fail_A$ from A, and A is exactly the node that sends the message request making B turn its state into GRANT, then, if B hasn't determined its color, B will return to previous state of UNSET1 or UNSET2. On the other hand, if B has determined its color, it will return to state SET.

However, if A doesn't receive any message $grant_B$ or $reject_B$ from its one-hop node B within a certain time d_A, node A will broadcast $request_A$ again. When A receives grant and reject from other nodes, it can estimate message delay in terms of the time difference between sending and receiving message. If the estimated value is larger than the current value d_A, it will be copied to d_A, otherwise remain d_A unchanged.

After node A has received all message grant replied by its one-hop neighbor, the node A can determine its own color according to the color value chosen by those nodes contained in message grant and its one-hop neighbor nodes. Then, all one-hop neighbor nodes which include the cluster nodes and the adjacent cluster head nodes saved in the list of nodes, are numbered starting from one as color offset value of these nodes. That is, assume that the determined color value of cluster head A is two and assigns the color value three to its ordinary cluster node c, so the true color value of node c is 2-3 as shown in Fig. 3.

In Fig. 3, node A has determined its color is two B is four. The list of neighbor nodes of A contains the ordinary node a, b and c belonging to this cluster. Meanwhile, the list of neighbor nodes of B contains the ordinary node e, f and g and so on. The head nodes have assigned color offset values for the nodes for its list. As a consequence, the true color of a- > A is 2-1, A- > B is 2-0 and B- > A is 4-0.

Function pseudo-code is as follows:

```
GenerateColor()
{
node.c=node.getMinColor();
//The decision of A self color
//Determining the color of other nodes in the cluster of A
for(int i=1; i< node.neighbor.length; i++)
{
neighborColor[i].id=node.neighbor[i].id;
neighborColor[i].color= node.c + i;
}
}
```

Function description:

getMinColor()：If the default color value of node A and the color values of its neighbors of two-hop are not repeated, then A retains its own color value. If repeated, A selects the smallest integer which do not conflict with the color values of its neighbors within two hops as its new color.

After the colors of cluster nodes have been determined, if there are still undecided colors in the one-hop neighbor nodes of A, A turns to the SET state and broadcasts message set_A to its all one-hop neighbors. The message contains its determined color values and the color offset values of its one-hop neighbor nodes.

The ordinary node i which is in the same cluster with a records their cluster color values and their color offset value after it has received the message set_A. At the same time, node i returns message $done_i$ to A. After the T_A time, if A has not received message $done_i$, A will broadcast message set_A again. The adjacent cluster head B of A updates its own information in adjacent nodes table after it has received the message set_A from A.

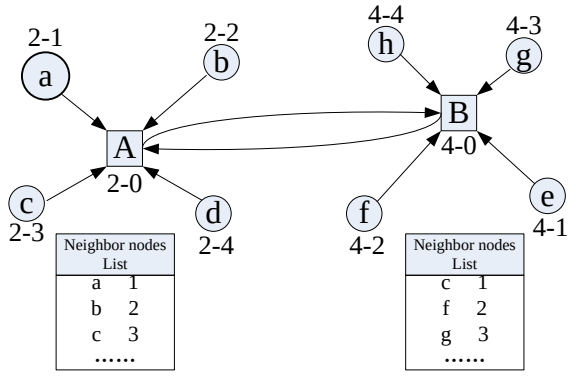

Fig. 3 The example of node color values.

4. Simulation Experiment

OMNET++ (Objective Modular Network Testbed in C++) developed by Andras Varga in 1992 was a powerful network simulation software, which was a cross-platform, open-source simulation environment, mainly for network communication, protocols, multiprocessor and distributed processing system

modeling and assessment of complex software system performance. This paper focuses slot assignment algorithm simulation, mainly examining the correctness of slot assignment algorithm, algorithm efficiency and the relationship between the network sizes.

Suppose there are more than one unit in the residential building, each unit building has 20 floors. According to the network topology in the first quarter, every two layers are placed one node, which put 30 nodes in total (cluster head nodes only are considered when simulating). Each node can access its adjacent other cluster head nodes on the physical location. The node x-y denotes the nodes in the y layer of x unit ensuring that the number of color between two-hop is different for 30 nodes. One specific color distribution of the results is shown in Table 1. The c in the s(c) indicates the final color value of node. The assignment results show that this algorithm can ensure the final color values of each node are different with the color values of their two-hop neighbor nodes.

The data collector is placed in each unit. The result of time slot assignment is shown in Fig. 4 along with the increase in the number of units. In the experiment, four units are compared with five units. The figure shows the relationship between time slot assignment and network size. It can be seen from the figure that the number of slots increases with the increasing number of units making no difference with the number of floors.

5. Conclusions

The wireless sensor networks used for meter reading system in the living quarter have many differences with the traditional wireless sensor network. It uses the meter as the sensor nodes and has characteristics of a fixed topology, small network change and higher message delay tolerance. Therefore, in the initial stage of establishing networks, each node is allocated a fixed time slot, thereby ensuring conflict-free communication. After it analyzes the topology of meter reading system in the living quarter, a distributed slot assignment algorithm is put forward based on the strong edge coloring algorithm in figure. The analysis shows this algorithm can assign distributed time slot for all nodes in a short period of

Table 1 The result of color assignment.

node1_1 s(11)	node2_1 s(8)	node3_1 s(5)
node1_2 s(6)	node2_2 s(9)	node3_2 s(7)
node1_3 s(1)	node2_3 s(12)	node3_3 s(10)
node1_4 s(4)	node2_4 s(8)	node3_4 s(6)
node1_5 s(9)	node2_5 s(3)	node3_5 s(5)
node1_6 s(7)	node2_6 s(12)	node3_6 s(11)
node1_7 s(6)	node2_7 s(10)	node3_7 s(8)
node1_8 s(11)	node2_8 s(9)	node3_8 s(5)
node1_9 s(4)	node2_9 s(7)	node3_9 s(3)
node1_10 s(1)	node2_10 s(5)	node3_10 s(6)

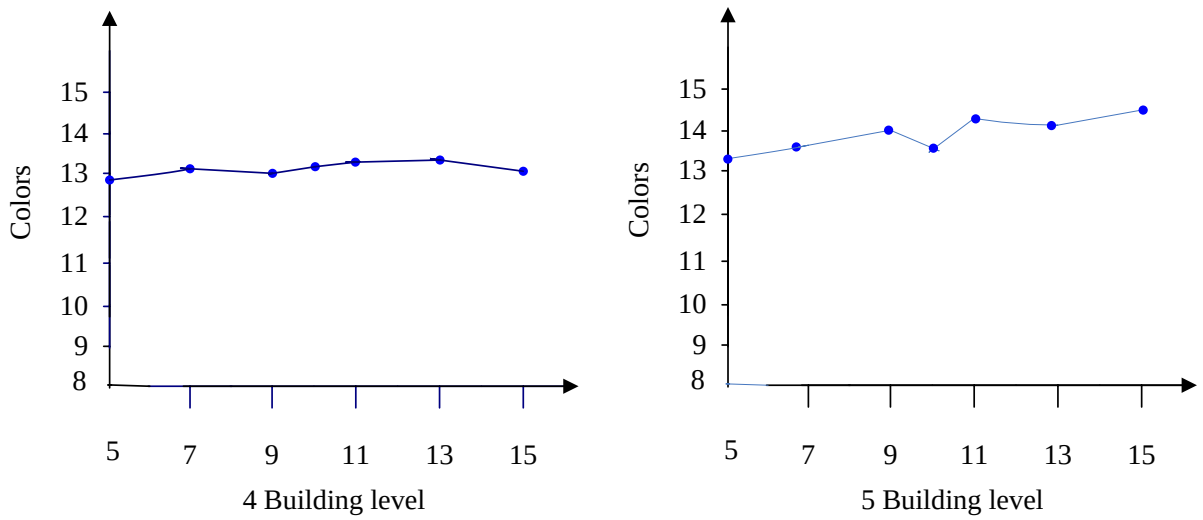

Fig. 4 Slot assignment and network size.

time. Many experiments have shown that this algorithm can assign time slot for nodes stably ensuring the communication with no conflict. Simulation experiments show that the time complexity of distributed time slot assignment algorithm is associated with an increased number of units, and don't have much relationship with the increase of floors.

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Journal of Communication and Computer 11 (2013) 1440-1444

Modeling and Simulation of Recursive Least Square Adaptive (RLS) Algorithm for Noise Cancellation in Voice Communication

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Received: October 25, 2013 / Accepted: November 16, 2013 / Published: November 30, 2013.

Abstract: In this paper a module consisting of a RLS (recursive least square) filter is modeled and verified to eliminate acoustic noise, which is a problem in voice communication. In this work the ANC (acoustic noise cancellation) is modeled using digital signal processing technique especially Simulink Blocksets. The needed algorithm code is generated in Matlab Simulink programming. At the simulation level, results of simulink implementation prove the module behavior for cancellation of noise in voice communication using the RLS adaptive algorithm. The main scope of this paper is to implement the module in real time onboard an autonomous DSK C6713 card in the future work, benefiting the low computational cost and the simplicity of the implementation using simulink programming.

Key words: RLS filter, adaptive algorithm, acoustic noise, ANC, digital signal processing.

1. Introduction

In telecommunications engineering technology, many applications have been developed around signal processing. Some of them were mainly part of large auditorium halls, terminals connected to wired networks and GSM mobile network in the automotive environment and involved waves filtering either at transmission side or at receiving side. This is why adaptive filters were developed and tested long before by the use of analog bench platforms until a digital based technique took place, the DSP (digital signal processing). This new technique allows better signal filtering design and found its benefits in high fidelity audio systems or speech networks.

Acoustic noise takes place whenever a loudspeaker is placed near a microphone in a full-duplex communication application. This is the case in speaker-phones, audio and video conferencing, desktop communication and many other communication scenarios.

Especially hands-free mobile communication and kits for cars are becoming increasingly important due to safety regulations introduced in more and more countries [1].

In all those and similar communication scenarios, the voice from the loudspeaker is certainly picked-up by the microphone and transmitted back to the remote speaker as shown in the next figure. This makes the remote speaker hear his/her own voice distorted and delayed by the communication channel, which is known as noise.

The longer the channel delay, the more annoying the noise becomes until it makes natural conversation impossible and decreases the perceived quality of the communication service. It is therefore absolutely necessary to avoid transmitting back the noise

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picked-up by the microphone.

Modern full-duplex communication systems make use of an ANC (acoustic noise canceller) to prevent the noise from being transmitted back to the channel. The ANC is employed in each terminal, and has completely different requirements than the network noise canceller employed by the telephone network provider to eliminate the electric noise. The ANC basically estimates the noise and subtracts the estimated noise from the microphone signal as shown in the next figure. The resulting signal is transmitted to the far end speaker through the communication channel.

Different works of RLS adaptive algorithm for noise cancellation is presented [2-4].

In this work the ANC (acoustic noise cancellation) is modeled in Simulink using digital filters especially adaptive RLS (recursive least square) algorithm.

The paper is structured as follows: Section 2 presents digital adaptive filters for noise cancelling, Section 3 presents simulation results, and Section 4 concludes this paper.

2. Digital Adaptive Filters for Noise Cancelling

Developing a filter that is able to comply with the statistics of the signal is the main scope of adaptive filtering. Adaptive algorithm efficiency depends on three criteria that size up:

The complexity of computation and the amount of computation executed at each stage;

The behavior of speed adjustment that permits an adaptive filter to reach weiner solution;

The estimated error generated by the dissimilarity between the actual weiner solution and the adaptive algorithm resolution.

Adaptive cancellation of noise is the main pattern of adaptive filters.

2.1 Adaptive Filters

In this section we first go through an examination of the filter structure with an emphasis on FIR (finite impulse responses) filters. This is followed by a review of the wiener filter leading to the development of the LMS (least mean squares) algorithm.

A noise canceller is a closed loop linear adaptive filter used for direct system modeling. There are many different combinations of filters and algorithms, depending on the particular application requirements; from FIR to IIR (infinite impulse response) filters, from LMS to RLS (recursive least squares) algorithms[5]. For noise cancellation, there is a classical standard adaptive filter formation. The filter part is made up of the most commonly used structure: A FIR filter which is also known as a tapped delay line, non-recursive or feed-forward transversal filter, as shown in Fig. 1.

The FIR filter consists of a series of delays, multipliers and adders; has one input, $x(n)$, and one output, $y(n)$. The output is expressed as a linear combination of the delayed input samples:

$$y(n) = \sum_{k=0}^{N-1} w_k(n)x(n-k) \qquad (1)$$

Where $w_k(n)$ are the filter coefficients and N is the filter length. Therefore $y(n)$ is the convolution (inner product) of the two vectors $w(n)$ and $x(n)$.

In this paper we will only consider RLS filters for noise cancellation.

2.2 Adaptive Noise Cancellation

One of the adaptive filter applications is the adaptive noise canceller. Figs. 2 and 3 describe its structure where the desired response is composed of an original

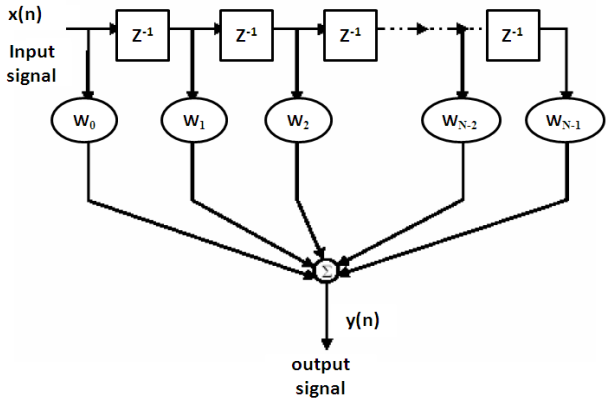

Fig. 1 FIR filter structure.

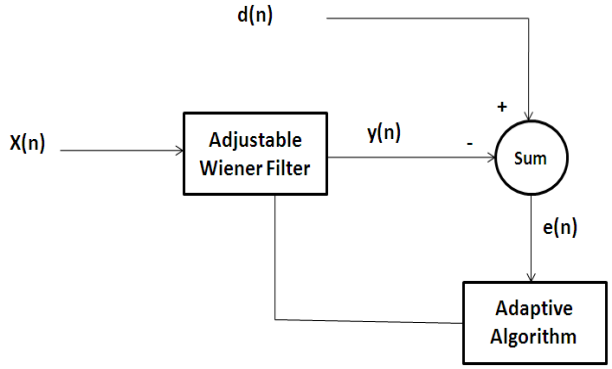

Fig. 2 Adaptive filter structure.

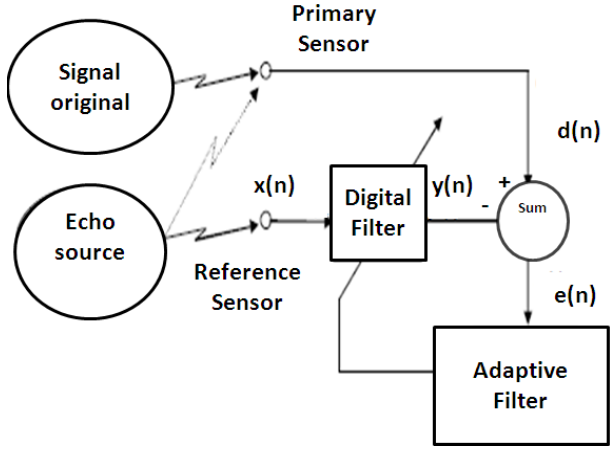

Fig. 3 Block diagram of the acoustic noise canceller.

signal plus the noised, which is uncorrelated with the signal.

The filter input is a sequence of a noised signal which is correlated with the noised signal in the desired signal.

By using the RLS algorithm inside the adaptive filter, the error term $e(n)$ produced by this system is then the original signal with the noise signal cancelled [6].

2.3 RLS Algorithm

In Fig. 4, the RLS filter block implements an adaptive RLS (recursively least-square) filter, where the adaptation of filter weights occurs once for every block of samples.

The block estimates the filter weights, or coefficients, needed to convert the input signal into the desired signal.

Connect the signal you want to filter to the input port. This input signal can be a sample-based scalar or a

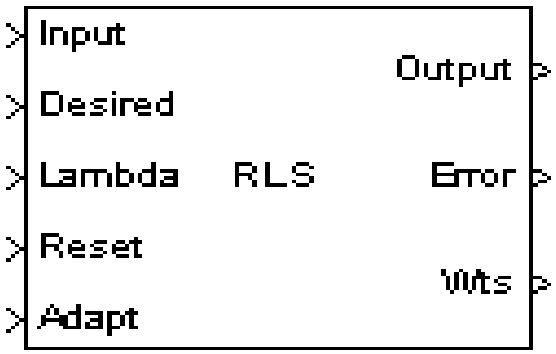

Fig. 4 RLS Filter block [7].

single-channel frame-based signal.

Connect the signal you want to model to the desired port. The desired signal must have the same data type, frame status, complexity and dimensions as the input signal.

The output port outputs the filtered input signal, which can be sample or frame based. The error port outputs the result of subtracting the output signal from the desired signal.

Hence, we define the primary input signal to be a colored with the noise of the measurement $y(n)$ and the reference signal to be the measurement itself.

We then apply the following modified normalized RLS algorithm which Tracks the desired solution.

$$y(n) = \hat{w}(n-1).x(n) \tag{2}$$

$$e(n) = d(n) - y(n) \tag{3}$$

$$\hat{w}(n+1) = \hat{w}(n) + \mathrm{k(n)^H\, e(n)} \tag{4}$$

$$k(n) = \frac{\mu^{-1} p(n-1) X(n)}{1 + \mu^{-1} X(n)^H p(n-1) X(n)} \tag{5}$$

$$p(n) = \mu^{-1} p(n-1) - \mu^{-1} k(n) x(n)^H p(n-1) \tag{6}$$

where μ^{-1} denotes the reciprocal of the exponential weighting factor.

The variables are as follows:

3. Simulation Results

3.1 Noise Canceller Modeling under Simulink

In this work we modeled the system shown in Fig. 5

Table 1 Table variable of RLS filter.

Property	Present
n	The present step of the algorithm
$x(n)$	The input at step n
$P(n)$	The inverse correlation matrix at step n
$y(n)$	The filtered output at step n
$e(n)$	The estimated error at step n
$d(n)$	The desired answer at step n
μ	The variable forgetting factor to adjust. Fulfills $0 < \mu < 1$

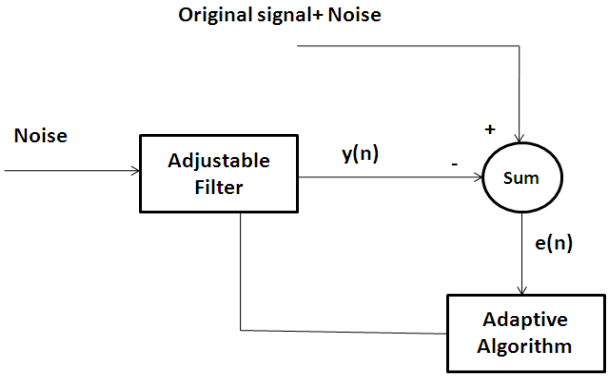

Fig. 5 Noise canceller system.

under Simulink Blockset. We also used an audio data with 8,000 Hz sampling rate.

3.2 Simulink Results

In the following graphics (Figs. 6-8), we observe the input signal (the original signal with noise) and how this noise is removed from the original signal after crossing by the "noise cancellation RLS Filter" module, knowing the noise signal has less amplitude than the original signal.

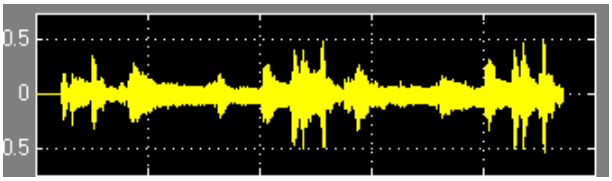

Fig. 6 Result obtained using simulink simulation (original signal, variable forgetting factor is $\mu = 0.5$).

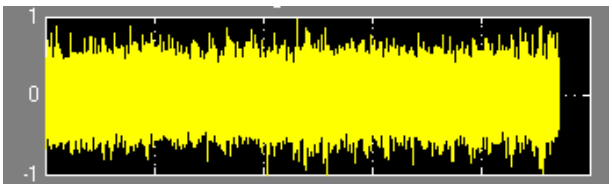

Fig. 7 Result obtained using Simulink simulation (Noised signal, Variable Forgetting Factor is $\mu = 0.5$).

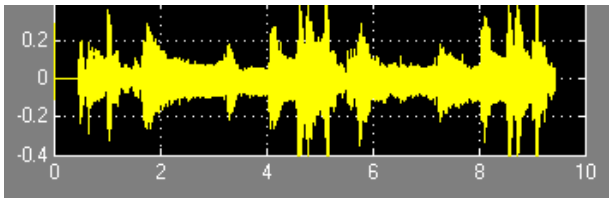

Fig. 8 Result obtained using Simulink simulation (filtered output, variable forgetting factor is $\mu = 0.5$).

It is also showing the filter coefficients, demonstrating how the signal is filtered, and the result is an output signal with less amplitude than the input signal and without noise.

The effect of modifying the variable forgetting factor, the filter length, the delay value on the convergence rate and obtainable performance is tested[8, 9]. The noise signal is switched between an input signal - a wav file - and a square wave.

It should be verified that a shorter filter length is required to obtain the desired cancellation while using the input signal, a wav file. Unofficial hearing tests should prove that the system is working properly: The periodic signal is almost cancelled whereas the speech maintains its natural quality.

4. Conclusions

In this paper, we have tried to modeling and implement a RLS adaptive filter module using Simulink Blocksets. This module, consisting of software blocks rather than electronic blocks, was specifically designed to provide noise cancellation in a voice communications system to achieve ideal sound reproduction as in high-fidelity systems.

In the future work we will implement this module in real time onboard an autonomous DSK C6713 card.

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Journal of Communication and Computer 11 (2013) 1445-1451

Passive Analogue Filters Synthesis Using MatLab

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Received: November 06, 2013 / Accepted: November 15, 2013 / Published: November 30, 2013.

Abstract: In this work was developed a MatLab code to obtain the passive elements' values of low pass prototype circuit Butterworth or Chebyshev type I. The influence of source and load resistors is used to obtain the input impedance circuit. The continuous fractionation method is applied to the input impedance which leads to a ladder LC circuit, the circuit has the frequency response equals to the transfers function Butterworth or Chebyshev for any source and load resistance. To validate the code, the obtained values were compared with the literature tables, although those tables are collared to 1 Ω resistors. The code allows any source and load resistors values circuit synthesis and the circuits were validated by simulation circuit program.

Key words: Passive filters prototype; Butterworth; Chebyshev; MatLab; continuous fractionation method.

1. Introduction

To perform the synthesis of analog circuits the designers normally use filters prototypes tables with limited conditions of generator resistance and load resistance [1, 2]. Designers are conditioned to the specifications that each bibliography has available when using the tables of prototypes. The theoretical method that allows the preparation of these tables can be found in Ref. [3].

Having an application that allows to synthesizing filters prototypes for general conditions of generator and load resistors and for general filter specifications is a tool that facilitates the work of the circuit designers. The code of this application, after being implemented in the function form permits to obtain the values of the LC ladder circuit parameters given desired specifications.

It is intended to present a code developed in MatLab that allows us to implement a Butterworth or Chebyshev type I filters. The transfer function is easily obtained using the MatLab signal processing toolbox. However, the filter design must take into account the effects of electrical resistance of the source and the load resistance. A new transfer function is obtained as an aid for calculating the input impedance of the system, this input impedance has already taken into account the effects of load resistance and maximum power transfer between the generator and load. The circuit LC elements of synthesizing ladder circuit can be obtained through the continuous fractionation method.

In this paper the Section 2 describes the theoretical basis to obtain a prototype circuit taking into account the transfer function and the generator and load resistors. In Section 3 the description of the MatLab code in which are given the values of LC elements of the prototype synthetize circuit is affected. Section 4 presents the results of calculations that the code developed and performs validation using examples in circuit simulation. Section 5 presents the conclusions of this work describing the limitations and advantages of the code.

2. Theoretical Background for the Used Method

2.1 Circuit Load Impedance

The transfer function of the Butterworth and the

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Chebyshev type I filter is specific for systems without load resistance. In Fig. 1 we have the system that represents the lossless filter coupled to the source and the load resistance [3].

The input and output relation is given by:

$$\left|\frac{V_0(j\omega)}{V_i(j\omega)}\right|^2 = \frac{R_L R_{11}}{|R_s+Z_{11}|^2} \quad (1)$$

Using the auxiliary function defined by Ref. [4]:

$$|A(j\omega)|^2 = 1 - 4\frac{R_s R_L}{(R_s+R_L)^2}\left|\frac{V_0(j\omega)}{V_i(j\omega)}\right|^2 \quad (2)$$

And using the relation $Z_{11} = R_{11} + jZ_{11}$, one obtain:

$$|A(j\omega)|^2 = \frac{|R_s-Z_{11}|^2}{|R_s+Z_{11}|^2} \quad (3)$$

Remembering that $|A(j\omega)|^2 = A(j\omega)A(-j\omega)$ we can extract the auxiliary function in the Laplace domain as function of source and input impedance:

$$A(s) = \pm\frac{R_s-Z_{11}(s)}{R_s+Z_{11}(s)} \quad (4)$$

And in turn we obtain the input impedance of the system regarding the load resistance embedding in auxiliary function:

$$Z_{11}(s) = \left[\frac{R_s-A(s)}{R_s+A(s)}\right]^{\pm 1} \quad (5)$$

The obtained $Z_{11}(s)$ by the Eq. (5) is taken directly using the Eq. (2), where the used transfer Eq. (1) is obtained from the generic functions Butterworth or Chebyshev.

$$\left|\frac{V_0(j\omega)}{V_i(j\omega)}\right|^2 = \frac{V_0(j\omega)V_0(-j\omega)}{V_i(j\omega)V_i(-j\omega)} = \frac{b(s)b(-s)}{a(s)a(-s)} \quad (6)$$

where $b(s)$ and $a(s)$ are polynomials function in the Laplace domain of the numerator and denominator, respectively.

2.2 Continuous Fractionation Method

The input impedance is in its general form a rational function of polynomials in the Laplace domain. We can decompose this rational in the Eq. (7) when the degree of the numerator is less than the degree denominator:

$$\frac{N(s)}{D(s)} = \frac{1}{q(s)+\frac{r(s)}{N(s)}} \quad (7)$$

where $q(s)$ and $r(s)$ are the quotient and remainder of the polynomial division. The $r(s)$ degree is lesser than $N(s)$ therefore we can repeat the process until the remainder being a polynomial of degree zero.

In the Butterworth and Chebyshev transfer functions the input impedance after decomposition by continuous fractionation method always gives the quotient $q(s)$ of degree one, and in the final fraction the denominator has degree one.

As presented in the following example obtained from third order Butterworth:

$$Z_{11}(s) = \frac{2s^2+2s+1}{2s^3+2s^2+2s+1} = \frac{1}{s+\frac{1}{2s+\frac{1}{s+1}}} \quad (8)$$

2.3 Construction of LC Ladder Circuit

In the process described in the previous subsection the final denominator can be interpreted by a series between one coil and a load resistance or by a parallel between one capacitor and a load resistance, yielding two kinds of circuit, with a coil series or a capacitor parallel, correspondingly, presented in Fig. 2, where the load resistance is not represented.

The example of Eq. (8) corresponds to a circuit where the latter denominator may be an admittance of parallel of C1 = 1F and R = 1 Ω, which in turn is in series with the impedance of L = 2H and finally is in parallel with admittance C2 = 1F, translated in the circuit of Fig. 3:

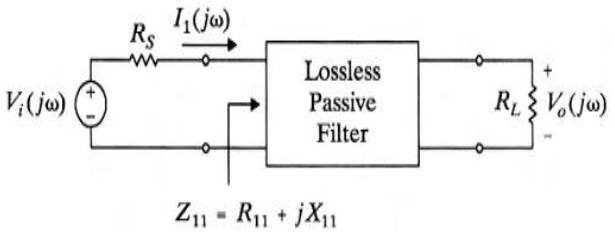

Fig. 1 Generic system with source and load resistance.

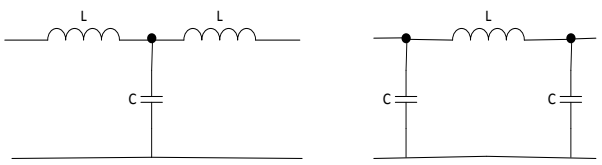

Fig. 2 Circuitry, (a) series inductor "T" e; (b) parallel capacitor "π".

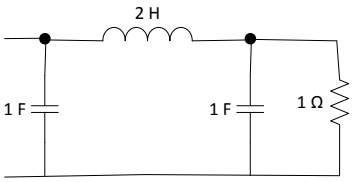

Fig. 3 Correspondent circuit for expression (8).

3. Code Description

The code developed was made in the MatLab language using the potential of the functions of "Signal Processing Toolbox".

3.1 Butterworth and Chebyshev Coefficients Calculation

The buttap() or cheb1ap() MatLab functions generate the zeros, poles and gain of analogue filters Butterworth and Chebyshev, respectively. Effecting the transformation of zero-pole transfer function we obtain the polynomial coefficients of the transfer function:

```
[z, p, k] = buttap(N);
[b, a] = zp2tf(z, p, k);
[z, p, k] = cheb1ap(N, Ap);
[b, a] = zp2tf(z, p, k);
```

3.2 Polynomial b(-s) and a(-s) Coefficients Calculation

It is necessary to determine the polynomial *b*(-*s*) and *a*(-*s*) coefficients for the transfer function of the system, as Eq. (6), which are used for auxiliary function *A*(*s*) calculation, obtained through the code:

```
a_sim = zeros(1, length(a));
b_sim = zeros(1, length(b));
for i = length(a):-1:1
a_sim(i) = a(i)*(-1)^(i+N+1);
b_sim(i) = b(i)*(-1)^(i+N+1);
end
```

3.3 Auxiliary Function A(s) Calculation

For A(s) calculation it is necessary first to calculate the $|A(j\omega)|^2$ using the Eq. (2). In the code the auxiliary function is separated in numerator and denominator polynomial coefficients fashion.

```
A_num=conv(a,a_sim)-conv(b,b_sim)*4*RsRl/(Rs
+Rl)^2;
A_den=conv(a,a_sim);
for i=1:length(A_num)
ifabs(A_num(i))<0.00001
A_num(i)=0;
end
if abs(A_den(i))<0.00001
A_den(i)=0;
end
end
```

Where Rs and Rl are the source and load resistance values, in that order. To clear the numerical error for infinitesimal coefficients, those values are zeroed as in the "for" cycle.

Then the zeros/poles positive and negative are grouped to achieve the corresponding numerator and denominator polynomials of A(s) and A(-s) functions, respectively:

```
z = (roots(A_num));
p = (roots(A_den));
z_pos = z(z>=0);
z_neg = z(z<0);
p_pos = p(p>0);
p_neg = p(p<0);
if length(z_pos)~=N
z_pos = [z_pos;zeros(N-length(z_pos),1)];
end
if length(z_neg)~=N
z_neg = [z_neg;zeros(N-length(z_neg),1)];
end
if length(p_pos)~=N
p_pos=[p_pos;zeros(N-length(p_pos),1)];
end
if length(z_neg)~=N
p_neg=[p_neg;zeros(N-length(p_neg),1)];
end
NumS=poly(z_neg);
NumnS=poly(z_pos);
DenS=poly(p_neg);
```

```
DennS=poly(p_pos);
```

In the previous code the technique of grouping zeros/poles positive and negative is fallible to null values, so it is necessary to add zeros in these cases.

Input impedance calculation

The input impedance of the system is calculated by the Eq. (5):

```
exp=-1;
Zin_num = Rs*(DenS-NumS)*exp;
Zin_den = (DenS+NumS)*exp;
```

Where the "exp" parameter determines the use of positive or negative exponent of Eq. (5).

Continuous fractionation method coefficients calculation

To carry out the continuous fractionation method is used MatLab deconv() function, which computes the polynomial division yielding a quotient and remainder of a division, as indicated by the Eq. (7). However, it is necessary to first check which of the two polynomials Zin_num and Zin_den have a higher degree. We use the length of arrays, after removing null elements, to determine the higher degree.

Making use of example Eq. (8) we chose to store into the variable coef the coefficients values of fractionation according to Eq. (9):

$$Z_{11}(s) = \cfrac{1}{\text{coef}\ (1)s + \cfrac{1}{\text{coef}\ (2)s + \cfrac{1}{\text{coef}\ (2)s + \text{coef}\ (3)}}} \qquad (9)$$

The code to calculate the coefficients is next presented:

```
num = length(Zin_num);
den = length(Zin_den);
coef = zeros(1,N+1);
for i = 1:num-1
Zin_num = Zin_num(find(Zin_num));
Zin_den=Zin_den(find(Zin_den));
num=length(Zin_num);
den=length(Zin_den);
if num>=den
[q,r]=deconv(Zin_num,Zin_den);
if i==N
coef(N,i:i+1)=q;
else
coef(N,i)=q(1);
end
Zin_num=Zin_den;
Zin_den=r;
else
[q,r]=deconv(Zin_den,Zin_num);
if i==N
coef(N,i:i+1)=q;
else
coef(N,i)=q(1);
end
Zin_den=Zin_num;
Zin_num=r(find(r));
end
end
```

4. Results

4.1 Prototype Butterworth and Chebyshev Type 1

The coefficients values obtained from developed code in Eq. (9) fashion for the orders 5, 6 and 7 circuits are listed from Tables 1-4. These coefficients can be used directly in the implementation of a filter, or in the

Table 1 Butterworth (*Rs* = 1 Ω e *Rl* = 1 Ω).

N	Coef(1)	Coef(2)	Coef(3)	Coef(4)	Coef(5)	Coef(6)	Coef(7)	Coef(8)
5	0.6180	1.6180	2.0000	1.6180	0.6180	1.0000		
6	0.5176	1.4142	1.9319	1.9319	1.4142	0.5176	1.0000	
7	0.4450	1.2470	1.8019	2.0000	1.8019	1.2470	0.4450	1.0000

Table 2 Chebyshev tipo I (*ap* = 0.1 dB), (*Rs* = 1 Ω e *Rl* = 1 Ω).

N	Coef(1)	Coef(2)	Coef(3)	Coef(4)	Coef(5)	Coef(6)	Coef(7)	Coef(8)
6	1.1468	1.3712	1.9750	1.3712	1.1468	1.0000		
7	1.1681	1.4040	2.0562	1.5171	1.9029	0.8618	0.7378	
8	1.1812	1.4228	2.0967	1.5734	2.0967	1.4228	1.1812	1.0000

Table 3 Chebyshev tipo I (*ap* = 1 dB), (*Rs* = 1 Ω e *Rl* = 1 Ω).

N	Coef(1)	Coef(2)	Coef(3)	Coef(4)	Coef(5)	Coef(6)	Coef(7)	Coef(8)
6	2.1349	1.0911	3.0009	1.0911	2.1349	1.0000		
7	2.1546	1.1041	3.0634	1.1518	2.9367	0.8101	0.3760	
8	2.1666	1.1115	3.0936	1.1735	3.0936	1.1115	2.1666	1.0000

Table 4 Chebyshev tipo I (*ap* = 3 dB), (*Rs* = 1 Ω e *Rl* = 1 Ω).

N	Coef(1)	Coef(2)	Coef(3)	Coef(4)	Coef(5)	Coef(6)	Coef(7)	Coef(8)
6	3.4813	0.7619	4.5375	0.7619	3.4813	1.0000		
7	3.5045	0.7685	4.6061	0.7929	4.4641	0.6033	0.1721	
8	3.5185	0.7722	4.6390	0.8038	4.6390	0.7722	3.5185	1.0000

series inductance "T" circuit or in parallel capacitance "π" circuit, where the highest coefficient corresponds to the load resistor placed in parallel at the end of each circuit. To validate all coefficients obtained by the code one just compare them with tables found in the literature [1-3, 5], that was validated.

4.2 Prototypes with Different Load Resistances

For other source and load resistance values, which are not found in literature, we tested the calculated coefficients from our code in simulation circuits. The code calculates the coefficients presented in Tables 5 and 6 for filters of order 5 with different values of resistors source and load resistance, equal to each other.

Two examples of circuits used with the values of tables, the Rs = Rl = 2 Ω, are presented in Figs. 4-5.

In Figs. 6 -7 the frequencies responses of the circuits are presented, where despite the fact that three curves in each figure are overlapping there is a small deviation between each, which is expected because the coefficients are rounded to 4 decimal places.

Table 5 Butterworth (*N* = 5).

	Coef(1)	Coef(2)	Coef(3)	Coef(4)	Coef(5)	Coef(6)
Rs = Rl = 1 Ω	0.6180	1.6180	2.0000	1.6180	0.6180	1.0000
Rs = Rl = 2 Ω	0.3090	3.2361	1.0000	3.2361	0.3090	0.5000
Rs = Rl = 50 Ω	0.0124	80.9017	0.0400	80.9017	0.0124	0.0200

Table 6 Chebyshev type 1 (*N* = 5) with *Ap* = 3 dB.

	Coef(1)	Coef(2)	Coef(3)	Coef(4)	Coef(5)	Coef(6)
Rs = Rl = 1 Ω	3.4813	0.7619	4.5375	0.7619	3.4813	1.0000
Rs = Rl = 2 Ω	1.7406	1.5238	2.2688	1.5238	1.7406	0.5000
Rs = Rl = 50 Ω	0.0696	38.0960	0.0908	38.0960	0.0696	0.0200

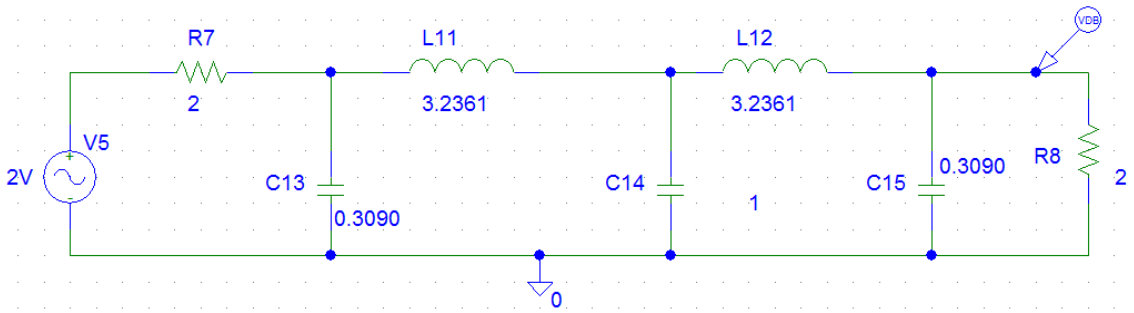

Fig. 4 Butterworth circuit, *N* = 5, *Rs* = *Rl* = 2 Ω.

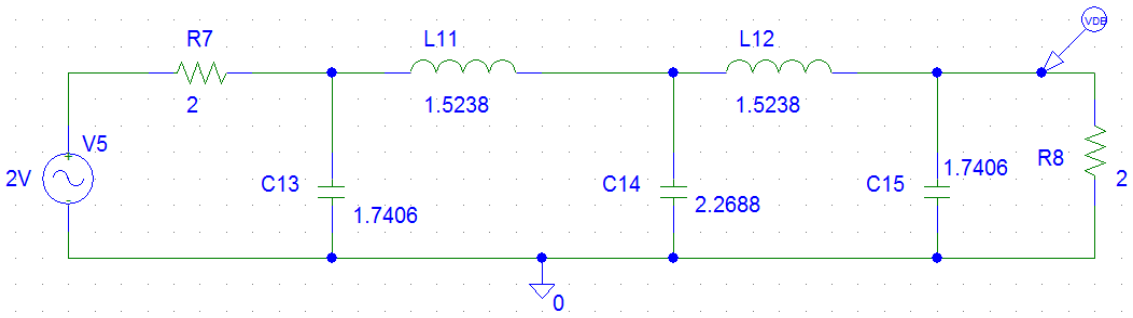

Fig. 5 Chebyshev circuit, *N* = 5, *Rs* = *Rl* = 2 Ω.

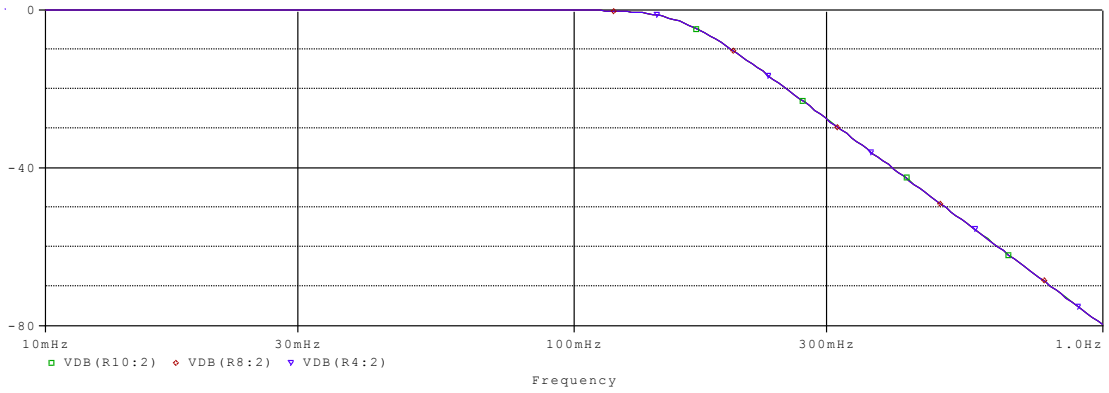

Fig. 6 Frequency response of Butterworth circuits.

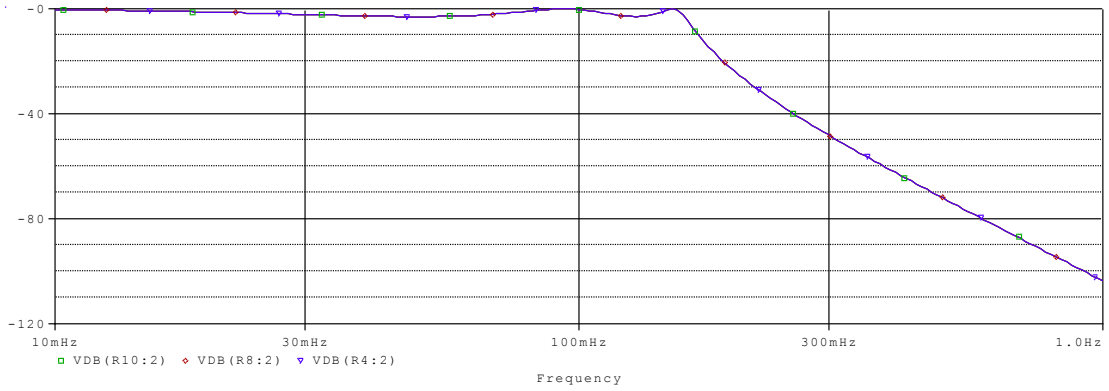

Fig. 7 Frequency response of Chebyshev circuits.

5. Conclusions

A code in MatLab was presented for synthesis of prototype low pass filters Butterworth and Chebyshev type I. The code has degree of freedom for choosing the order of the filter and the source and the load resistor, in the case of Chebyshev filter it also has the degree of freedom to select the maximum pass band ripple in dB

The results obtained are identical with the literature, nevertheless the code can compute any prototype within the degrees of freedom, which are more dynamic against the use of tables.

It was also validated that for different source and load resistance the code produces different circuits with identical frequency response simulation. Thus validating the coefficients values of the prototype circuit.

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Journal of Communication and Computer 11 (2013) 1452-1458

HIQMA: A Rigorous Healthcare ISO9001 Quality Management System

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Received: October 30, 2013 / Accepted: November 15, 2013 / Published: November 30, 2013.

Abstract: This paper describes HIQMA, an integrated, web-based, and fully automated healthcare institution quality management system. The system includes many applications, starting with a quality handbook for the individual beneficiary organizations and not ending by the development of service guidelines. It is based on a result-proven design approach that enhances medical and healthcare services. The different stakeholders are provided with a common framework for designing, implementing, evaluating and improving these services. HIQMA is scalable in the sense that additional professional development tools based on work service guidelines can be implemented.

Key words: Healthcare, QMS (quality management system), quality assurance, quality control, ISO, standardization.

1. Introduction

Constant upgrading of the quality of healthcare centers is a key priority at institutional, national, regional and international levels. Recent charted European agreements placed the objective of increasing the attractiveness of healthcare institutions and promoting medical tourism [1] as a key objective along with quality improvement requirements (e.g., the EU-OECD agreement on healthcare indicators [2], EUPHORIC Project [3], etc.).

To achieve such key objectives, most of the current systems follow the classical methodology of cyclic planning, implementation, assessment and review, and examine the process as a relative and contextual concept. That cyclic process in nature is depicted in Fig.1 [4]. The above approach is usually adopted to avoid the creation of a pervasive and unequivocal definition of healthcare quality. An effective QMS (quality management system) targets the systemic development and communication of a customer-focused mission, strategies and action plans. Thereby, listening and responding to customers' needs and expectations, empowering employees to keep improving and increasing their satisfaction with their work processes and environment, and gathering and analyzing KPIs (key performance indicators) to enhance organizational and process results are of immense importance for good governance of an institution [5].

Consequently, an integrated web-based HIQMA (healthcare institution quality management) system has been implemented to improve medical and healthcare

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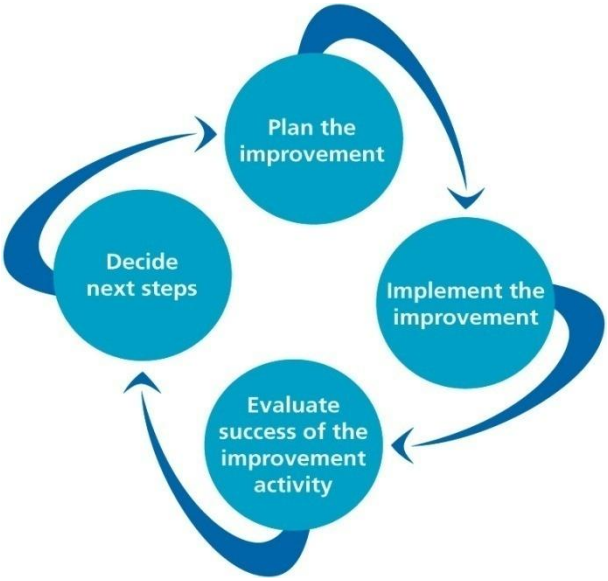

Fig. 1 Classical methodology of cyclic planning.

services. The system attributes include several applications, starting with a quality handbook for the individual beneficiary organizations, continuing with the reformed professional training and advisory services concepts, and ending with the developed service guidelines. In addition, scalability and customizability are intrinsic characteristics of the system. These attributes ensure that different stakeholders are provided with a common framework for designing, implementing, evaluating and improving these services.

This paper describes the functionality of HIQMA system as well as some of its attributes and services. Section 2 describes the system in details. Section 3 outlines the governance and standards compliance dimensions. Section 4 presents some results and impact assessments. Further enhancements are described in Section 5.

2. Tool Description

Managing quality performance requires a comprehensive approach that has a dynamic nature in terms of agility and customization. This becomes highly important when dealing with healthcare institutions as they must carefully consider and control their activities to ensure all quality requirements are met. The integrated web-based automated HIQMA system that was built, has been designed to assist such organizations in implementing and maintaining this comprehensive approach by delivering tools structured around the ISO 9000 family of international standards for quality management taking into consideration the special needs and features for healthcare services [6].

HIQMA is a centralized management system that provides a portal to critical quality information and facilitates quality performance improvement through requirement tracking, notifications and real-time management reporting. It has been designed to streamline and automate quality management processes of any medical organization and assist in the effective implementation of wide quality initiatives on a "use per need basis". The software system is 100% web-based, highly configurable QMS that helps organizations track, analyze, and report on quality management in addition to streamlining existing processes and enforcing their application.

The system was deployed for the first time in Lebanon in early 2011. Since then, the system has been deployed in 7 medical institutions covering 3 private hospitals with 100+ bed capacity, 2 polyclinics and 2 medical labs. As a part of the system's development and evolution plan, a new version of the software is installed every 6 months in all locations. Typically, the new software releases include bug fixes, further enhancements and new features. In an attempt to ensure customer satisfaction and continuous quality improvement, an annual on-line customer survey is conducted. The survey is comprised of 20 questions covering 4 distinctive areas: functionality, compliance, efficiency and quality control. A quantitative scale of 1-5 is used with 1 being poor and 5 being excellent. In the first survey conducted in early 2012, a total of 5 institutions responded to the survey and an average score of 3.90 was recorded. In the second survey conducted in early 2013, a total of 7 institutions responded to the survey giving the system an average score of 4.36. This suggests that the system has

evolved significantly and is a viable candidate for wider deployment and adoption by other medical entities. In the next sections, the main features of the system will be described in further details.

2.1 Web-Based Application

From a technical perspective, the system is web-based, with all of its features and their respective functionality accessible through any web browser. It can be hosted inside the healthcare institute's LAN (local area network) infrastructure with open or confined access from outside the establishment's premises. The system can also be hosted online using any preferred hosting service provider or cloud hosting services. In addition, it offers a deployment model for organizations preferring to outsource hardware and software maintenance. Roll-out of the system can be completed for any given location worldwide in less than 6h enabling users with a URL, username and password to access the system from –virtually– any Internet access point. According to recent findings, web-based interfaces reduce the learning curve of medical or administrative staff who can begin to work with the system shortly after installation and incorporate it in their daily tasks and activities [7].

2.2 Centralized Activities Management and Customization

Through a friendly GUI (graphical user interface), the system provides the user with a workplace that is easy to work with through a variety of summary screens, task menus and drop-down lists. These features are accessed by a regular user according to his/her assigned privileges and/or role(s).

A regular user may access a user specific task summary screen that summarizes the responsibilities in sequential order. Users can be presented with this screen upon login, ensuring single click access to their most critical information. Management personnel have access to a personalized menu that provides visibility over current activities and pending assignments of the medical staff tasks. Management system coordinators and senior personnel have access to a complete listing of tasks by location, department, region or corporation as a whole.

The system tracks "who" is doing "what", "when", "where" and "how". It does not just store this information; rather, it automates such information through notifications and tracking mechanisms. All tasks, forms and assignments can trigger an email notification to the appropriate responsible person. Every email notification includes a hyperlink that sends the user directly to the task detail screen within the system. This screen provides further instructions, downloads, as well as fields, to record activity completion and uploads related documentation. The system ensures nothing falls through the cracks with an escalating email notification feature. The system can be configured to escalate the email notification of tasks pending completion. This feature is extremely flexible and can be configured to send any number of emails to any number of people to ensure tasks are completed on time.

2.3 Embedded Forms and Processes

The application is pre-loaded with numerous forms, checklists and common processes for all the necessary activities that are common in almost all healthcare institutions. The availability of such material helps the user complete needed tasks and activities in a controlled manner where human mistakes are minimized. Detailed process description is always displayed whenever the user invokes or triggers any activity which involves that respective process. If multiple processes are involved within a specific operation, then all of them will be made available to the user for consultation, help and cross-checking. This makes the application a fail-proof approach, ensuring that quality requirements compliance is maximized and chance of making errors is minimized. This naturally leads to improved QoS (quality of service) and better risk management.

2.4 Flexible Reporting

The HIQMA system is designed to streamline the flow of information throughout the healthcare institution. Institutions can mirror their hierarchical structure within the database, and this enables data to flow from a site, to a department, to a unit, to institute-wide, to regional or other locations in the case of multi-center organizations. Each location, division, department or other type of unit can manage its structures independently, and can have varying levels of hierarchy.

Data within the system will roll-up to appropriate management levels instantly in real-time without the need for lengthy manual traditional processes and procedures. The system has a centralized reporting tool that makes sharing information easy. Users at all levels of the organization can generate reports that summarize performance status and requirements. All reports can be generated in the most popular formats (HTML, PDF, .DOC or .XLS). Reports can be configured online through the web-based interface. A screen-shot capturing the reporting panel is shown in Fig. 2.

2.5 Mobility

The user is provided with great mobility and agility where the system may be accessed from any computer or mobile device from anywhere as long as there is a connection to the hosting server (LAN, WLAN or Internet). This provides the users with instant access to data at all times. Mobility certainly improves business performance, increases organizational efficiency and decreases response time.

2.6 Security

The system has a robust security management console that enables access to the modules, locations and functionality to be controlled for each user and user group. System administrators, who have access to the security module, can manage user access and the views available to user groups, as well as view the history of user visits dates and time stamps. In addition, encryption of the user credentials and data is included upon login and throughout the authentication and authorization process.

The user/permissions module of the system allows a

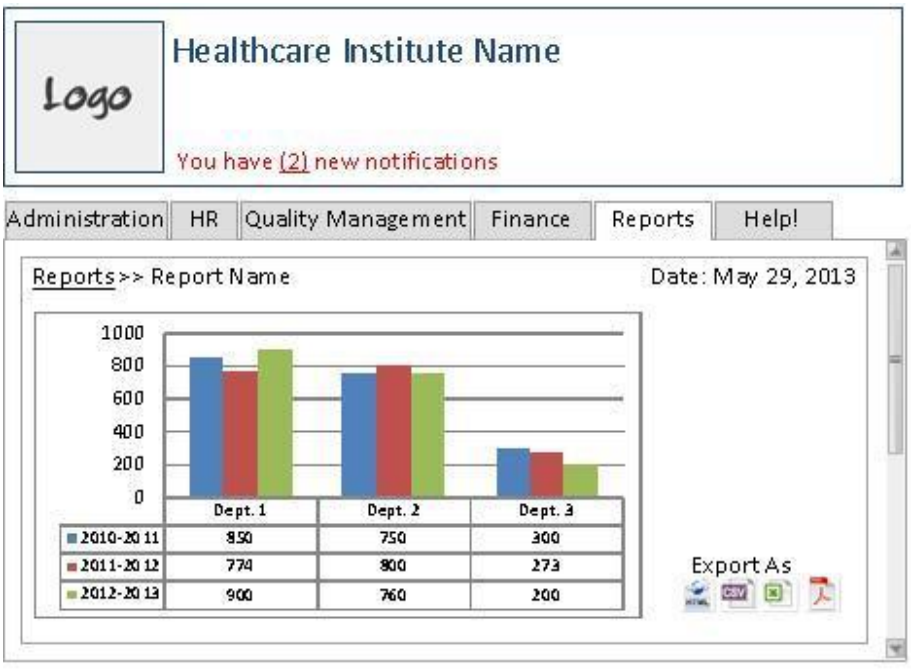

Fig. 2 Reporting panel screen-shot.

top level administrator to assign permissions and roles for each user individually or as part of a security group. The functional permissions of each user are assigned based not only on the actions he/she is supposed to perform, but also down to the data level he/she is required to manipulate. For example, two different users may have the same role and permissions but each can perform his/her permissions on a specified set or pool of data by department, patient, or others.

2.7 Multi-lingual Support

The system has a dynamic user interface that is available in multiple languages. Newly translated interfaces are continually being added. The system currently supports English, French, Arabic and Farsi languages. The system technology is developed in such a way that the interface's language can be changed by the user according to the languages requested by the medical organization. In addition, data entry in multiple languages is also currently supported. Although the system does not translate data, it does provide a centralized roll-up capability of data in multiple languages. This process is fully automated through a localization module which accesses the database that has tables of all systems strings which are visible to the end user.

3. Governance and Compliance

3.1 Governance

In any healthcare organization, small or large, adding, demoting or changing forms and procedures is a procedure by itself. The users will require training on the new procedures and forms, and the printed documents require replacement to reflect new changes.

The system's technical structure with respect to workplace, rules, forms and menus takes into consideration future changes and enhancements of the business rules and practices of the medical institution. Any updates to the forms or procedures are done directly on the system, and once committed, the institution ensures adherence to the new forms and rules instantaneously.

3.2 ISO Compliance

The software application is not only structured as per the ISO 9001 standards with all the modules that address each of its requirements, but also contains many unique features that facilitate on-going continuous improvements [8]. It is designed specifically for healthcare institutions implementing or maintaining a QMS based on ISO standards. The ISO standard is considered as a general purpose standard applicable across the industry [9]. In addition, it drastically improves internal or third party audit results by adhering to the ISO modules summarized in Table 1 [10].

4. Results and Impacts

So far, the system has been recently deployed in a number of healthcare institutions in addition to a number of medical colleges and universities. Certainly, each sector has its own flavor of the system but a number of common conclusions could be derived from their deployment and operations. Some highlights are:

- Seamlessly orientating the users to clearly understand and easily satisfy the quality needs;
- Continuing improvement in the institution by adopting quality as a philosophy. This is a crucial requirement for adopting a TQM (total quality management) approach which is essential for business sustainability;
- Presenting defined and consistent processes and guaranteeing their successful completion as long as processes are done in a timely manner according to the standards;
- Adhering to preventing instead of supervising, thus ensuring that the costs of preventive measures are less than those of close supervision or micro-management. This is a proactive step rather than a reactive one;

Table 1 A summary of supported ISO 9001 2008 requirements.

ISO 9001 2008 requirements	
Clause	***Title***
5.3	Quality policy
5.4.1	Quality objectives
5.4.2	Quality management system planning
5	Management responsibility
5.1	Management commitment
5.5.1	Responsibility and authority
5.5.2	Management representative
6.6.2	Competence, awareness and training
5.5.3	Internal communication
7.2.3	Customer communication
4.2	Documentation requirements
4.2.2	Quality manual
4.2.3	Control of documents
8.5.2	Corrective action
8.5.3	Preventive action
7.6	Control of monitoring and measurement devices
8	Measurement, analysis and improvement
8.2	Monitoring and measurement
8.2.3	Monitoring and measurement of processes
8.2.4	Monitoring and measurement of product
8.3	Control of nonconforming product
8.4	Analysis of data
4.2.4	Control of records
8.2.2	Internal audit
5.6	Management review
5.6.2	Review input
5.6.3	Review output

- Utilizing a single, institution-wide system to manage all quality management information and initiatives. This becomes especially relevant in multi-location institutions;
- Automating the tracking, management and notification of the QMS stakeholders;
- Providing web-based tracking forms, analysis tools and roll-up reporting to facilitate continual improvement and measurement of key performance indicators;
- Centralizing the management of quality related activities and requirements and driving the medical institution performance;
- Experiencing robust document control and management for all quality related procedures and policies.

The outlined findings are based on preliminary on-line surveys that were done by the institutions where the system was deployed and on thorough discussions with the various stakeholders through the formal review and evaluation process. The following lessons learned were also noted:

- A common—and rather classical – issue is faced in most of the institutions, which is related to the resistance to change, especially in institutions where some staff personnel have a low adaptation capability to non-paper based systems;
- Changes and updates in automated quality management systems belong in general to the service/product provider which limits the capability and the capacity of the institution to abrupt changes in running processes which might be needed in some cases where non-ordinary circumstances are present (ex: change management in risky zones);
- For institutions with low number of patients and specialties, the cost of such a system will increase the overhead and somehow lower the quality/price ratio. Usually, such institutions are oriented towards systems with fewer modules, thus leading to a limited access to all the benefits of the system;
- Institutions with simple—or no—information technology (IT) departments will face the problem of hosting and managing the system servers. Such institutions are advised to go with the cloud hosting solution to minimize the overhead and transfer the risks to the hosting service provider.

Many institutions that deployed this system found the need to update some of their forms, rules and procedures early in the definition phase. The structured and logical methodology the system uses can spot flaws in procedures and regulations. In addition, it allows the institution to do a major review on the consistency and integrity of its existing QM system.

5. Further Enhancements

The HIQMA system is open to a huge set of

enhancements in the future. Currently, we have three main enhancement features and propositions being studied.

The first enhancement is to develop an add-on module to the system that is able to collect data from multiple institutions and organizations. This pool of data will result in a knowledge base that will allow the analysis of quality management practices on national or international levels. It will also give insights on how institutions interpret and understand quality, as well as propose best practices and procedures.

The other enhancement is to allow healthcare institutions with well-established IT departments the capability of creating and designing their own forms and workflow from a graphical interface without the need to write code.

A long-term proposition is to add a "Learn Mode" module powered with artificial intelligence code that reads and interprets the system's technical logs to automatically propose enhancements to procedures and policies. The "Learn Mode" can be set to individual parts of the system or to the whole set of enabled modules.

6. Conclusion

The good healthcare service is not only a social responsibility, but also a good contributor to economic competitiveness and welfare in a global knowledge-based economy. Many challenges face medical services, including developing and upgrading the skills of the existing workforce, promoting labor mobility, diversifying customer base and–most importantly–planning and implementation of education and training services. All of the above require that the management of such programs be handled with care and innovation, on the one hand to maintain a quality culture in the institution, and on the other, to keep up with a the competitive edge of the services rendered.

The integrated web-based HIQMA system can meet these challenges and more. The system tackles the details of ISO standards and medical services peculiarities, and delivers a high quality, high performance package for use by the various institutes, irrespective of their specializations. Such an approach proved to be efficient, robust and reliable in all the sites where it was installed and tested. This aligns well with the findings of research suggesting that the implementation of software control systems is significantly associated with either improvements in or higher levels of quality of care as measured by process or outcome measures [11].

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Journal of Communication and Computer 11 (2013) 1459-1464

Spectrum Assignment on the Elastic Single Link

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Recieved: October 05, 2013 / Accepted: November 05, 2013 / Published: November 30, 2013.

Abstract: In elastic networking, the WDM fixed frequency grid is replaced by a more flexible structure, in which the spectrum is organized in frequency slots, and each traffic flow is assigned to an appropriate set of contiguous slots. The classical RWA (routing and wavelength assignment) problem is then replaced by the RSA (routing and spectrum assignment) problem. In this paper, we discuss the SA (spectrum assignment) problem in a single link, where it is not coupled to the routing problem, thus allowing for a better understanding of its dynamics. The best SA algorithm, taken as anyone who minimizes the average time it takes to provide total exhaustion of the initial available spectrum under incremental traffic, is shown to be a function of the traffic profile. It is shown that the greedy algorithm, which is unaware of the traffic profile, may impose severe performance penalties if the request rates increase with the number of requested slots. However, no penalty is incurred by more friendly profiles, like the uniform one.

Key words: Elastic optical networks, spectrum assignment, traffic-aware slot assignment, incremental traffic.

1. Introduction

The emergence of new services on the Internet will require future optical networks to transport traffic with differentiated QoS and bandwidth requirements. Although WRNs (wavelength routing networks) have brought several advantages to the transportation of heterogeneous client layer traffic when compared to first-generation optical networks, they still present inefficient optical spectrum utilization due to the granularity mismatch between the traffic demand and the rigid bandwidth granularity of WDM, especially in mixed line rate systems. Recently, several authors [1-3] have pointed out that it is possible to increase the spectrum efficiency of WRNs if a flexible method of spectrum allocation is accomplished. In this new type of network, referred to as EON (elastic optical network) or Gridless Network, the bandwidth assigned to a lightpath can span a flexible slice of the optical spectrum. Such flexibility allows a finer match between required and provided bandwidths, thus improving network spectral utilization. For simplicity, the spectrum partitioning into frequency slots of fine granularity has been proposed in EONs, whereas a lightpath may be established over an appropriate set of contiguous slots.

Due to the need to accommodate connections of heterogeneous frequency granularities, current methods of optimizing spectrum usage in WRNs may not be efficient when directly applied to EONs. For instance, it has been shown that the improvement on the path blocking probability when the First-Fit wavelength assignment is used instead of random is much more pronounced in EONs than in WRNs [4-6]. Actually, random spectrum assignment is very inefficient for heterogeneous-granularity traffic demand due to the resulting high likelihood of fragmentation of the remaining spectral resources.

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Another interesting result is the poor performance of the most-used algorithm if directly applied to gridless networks [5], as the sum of spectrum usage on a range of frequency band in EONs does not lead to the known compacting characteristic that makes the most-used one of the most efficient wavelength assignment algorithms in WRNs. In Ref. [4], the authors present an alternative method of accounting for the loss of capacity of heterogeneous-granularity path routes induced by a candidate assignment, thus generating a proposed metric to compare possible assignments of connections of given granularities.

A flexible spectrum assignment may also ease the inability of WRN's to establish cost-effective ephemeral routing and spectral assignments under failure events. For instance, in Ref. [7] the authors propose a cost-effective restoration mechanism in terms of spectral resource utilization, referred to as bandwidth squeezed restoration (BSR), in which, under a failure event, the backup path bandwidth may be reduced (i.e., squeezed) to a pre-defined required minimum amount established on the client requirement. This is conveniently realized in EONs due to their gridless characteristic, and enables a higher number of paths to be recovered when there are insufficient backup resources. In Ref. [8], the authors propose a protection mechanism that distributes the traffic in the network in some controlled way so that resources can be saved when compared to conventional dedicated protection and the required minimum amount of traffic, as proposed in the BSR scheme, can be guaranteed in the event of a failure.

In this paper we investigate the SA (spectrum allocation) problem in a new perspective. In Ref. [4], it has been shown that the number of contiguous unoccupied frequency slots determines the number of possibilities that future path requests can be inserted into the network, thus determining the path blocking probability. In this paper, however, instead of analyzing the blocking probability of path requests, we focus on the average time a set of contiguous vacant slots in the network is totally filled by future arriving permanent connections. The underlying idea is that any policy that minimizes the average time to thoroughly occupy a given spectrum range will be most efficient in the use of spectrum resources. For simplicity, in this paper we analyse a single link under incremental traffic demand. It will be shown that, depending on the bandwidth-request traffic profile and the number of contiguous vacant frequency slots, avoiding the accommodation of some traffic demands may be beneficial to minimizing the expected time for total slot utilization. This paper is an extended version of Ref.[9].

Section 2 discusses the motivation to focus on the single link and provides a formal statement of the problem and its general solution, as well as the instantiation of the general solution into some interesting cases for which the general solution yields a well-defined analytical result for the best algorithm(s). The performances of optimal solutions are compared with that of an intuitive, traffic-unaware algorithm, and penalties are derived and calculated in some cases. Section 3 discusses numerical results for some cases where no general-form solution has been found for the optimal algorithm. Section 4 concludes the paper.

2. Problem Statement and Solution

2.1 Problem Statement

In the WDM network, the RWA problem is essentially topological. For this reason, it vanishes in the single link, where there is only one possible routing, and all possible WA (wavelength assignment) algorithms yield the same performance. In the elastic network, though, this is not the case, as different spectrum assignment algorithms do yield different performances, even in the single link. The reason is that, while in the WDM network the spectrum mismatch loss is taken by the user, in the elastic network users are encouraged to demand only the amount of spectrum they actually need, leaving the network with the problem of making most efficient use of the available

fibre spectrum under a heterogeneous demand.

A formal statement of the problem is stated as follows. Let S be the number of available slots serving a single link, assumed to be sequentially contiguous, and let λ_i be the traffic intensity of requests for i contiguous slots, i = 1, 2, 3 …, for the purpose of setting up permanent connections in this link. The problem then asks for the strategies for accommodation or rejection of these requests that minimize the mean time to activate all slots of the spectrum.

2.2 Problem Solution

If accepted, an *i*-slot connection request must be accommodated in a void with *v* slots, with $v \geq i$. If $v = i$, the accommodation will suppress the void. If $v = i + 1$, it will leave a void with size 1. If $v > i + 1$, according to where the connection is accommodated within the void, it may lead either to a single residual void with size $(v - i)$ or to two separate voids with sizes v_1 and v_2 such that $v_1 + v_2 = v - i$. In the latter case, notice that all subsequent allocations into two separate voids might also be made if they were contiguous in a single void. On the other hand, the single void may also accommodate some requests that could not be accommodated into two separate voids with the same total number of slots. Therefore, nothing is gained when a request is accommodated in the middle of a void, generating two separate new voids. For this reason, we shall assume that all accepted requests will be accommodated in the smallest frequencies of a single void, without any loss of generality or optimality.

This argument proves the optimality of first-fit accommodation with priority given to the smallest (largest) frequencies, thus corroborating the optimality of a first-fit slot assignment algorithm. However, it does not mean that all requests should be accommodated, as the accommodation of a request for a small number of slots may produce the blocking of larger demands for spectrum later on. In order to minimize the mean time to activate all slots of the available spectrum, one must then determine whether to accept or reject a request according to the sizes of the request and the residual spectrum void at the time of request.

For each void size $s \leq S$, an allocation algorithm A applies a policy $P^s = (p_1^s, p_2^s, \dots, p_s^s)$, $p_i^s \in \{0,1\}$, whereby a request for *i* contiguous slots will be rejected if $p_i^s = 0$ and accepted if $p_i^s = 1$. The set of policies $\{P^1, P^2, \dots, P^S\}$ defines the algorithm. The greedy algorithm is defined by $P_G^s = (1, 1, \dots, 1)$ for any *s*, meaning that all feasible requests are accepted. This feature makes it unaware of the traffic distribution, simplifying its operation, but with no guarantee of optimality in the speed of total spectrum utilization. We wish to investigate the performance price that must be paid for this operation bonus.

Let $T(s, A)$ be the mean time it takes for algorithm *A* to fill a void with size *s*:

$$T(s, A) = \frac{1 + \sum_{i=1}^{s-1} p_i^s \lambda_i T(s-i)}{\sum_{i=1}^{s} p_i^s \lambda_i} \qquad (1)$$

where the first term $(1/\sum_{i=1}^{s} p_i^s \lambda_i)$ is the mean waiting time for the arrival of the first acceptable request under policy $\boldsymbol{P}^s$, and the second term $(\sum_{i=1}^{s-1} p_i^s \lambda_i \, T(s-i)/ \sum_{i=1}^{s} p_i^s \lambda_i)$ is the average, over all possibilities for the size*i* of the first accepted request, of the time to fill the resulting residual void of size$(s - i)$.

Now let us consider the minimal of $T(s, A)$over all algorithms:

$$T_{min}(s) = min_A \, T(s, A) =$$
$$= min_{\boldsymbol{P}^s} \frac{1 + \sum_{i=1}^{s-1} p_i^s \lambda_i T_{min}(s-i)}{\sum_{i=1}^{s} p_i^s \lambda_i} \qquad (2)$$

where the minimizing value(s) of P^s yield the initial optimal policy(ies) for void size *s*.

2.3 Some Examples and Special Cases.

A void with size 1 can only be filled in finite time under policy $P^1 = (1)$, which will take a mean time $(1/\lambda_1)$ to do the job. Therefore:

$$T_{min}(1) = 1/\lambda_1 \qquad (3)$$

Plugging Eq. (3) into Eq. (2) recursively, it is then possible to derive $T_{min}(s)$ and the optimal policies for

s = 2, 3… S. Under an optimal algorithm, an optimal policy is used for each $s \in \{1, 2, \ldots S\}$.

Lemma 1. If λ_s is positive and P^s is an optimal policy, then $p_s^s = 1$.

Proof. In (1), λ_s adds only in the denominator, multiplied by p_s^s; and is absent in the numerator.

Example 1: S = 2.

Lemma 1 implies that $p_2^2 = 1$ in all optimal policies. Then, using Eq. (3) in Eq. (2) for s = 2 yields:

$$T_{min}(2) = min_{p_1^2} \frac{1+p_1^2}{p_1^2\lambda_1+\lambda_2} = \min\left(\frac{1}{\lambda_2}, \frac{2}{\lambda_1+\lambda_2}\right) \quad (4)$$

Notice that $p_1^2 = 1$ minimizes $T_{min}(2)$ in Eq. (4) if and only if $\lambda_2 \leq \lambda_1$. This is then a necessary condition for the greedy policy (11) to be an optimal policy, and consequently for the optimality of the greedy algorithm for any $S \geq 2$. If $\lambda_2 > \lambda_1$, the optimal policy for s = 2 is (01) and the greedy algorithm will not be optimal. If we define a "traffic greediness price" $G(S)$ as the ratio between the mean time the greedy algorithm takes to fill a void with size S and the minimal of such time over all algorithms, then:

$$G(2) = \frac{2\lambda_2}{\lambda_1+\lambda_2}, \text{ if } \lambda_2 \geq \lambda_1 \quad (5a)$$

$$G(2) = 1, \text{ if } \lambda_2 \leq \lambda_1 \quad (5b)$$

As λ_2 s taken from λ_1 to infinity, notice that the greediness price increases from 1 to 2, implying that the greedy algorithm may take up to twice the time it would take to fill the void by a traffic-aware, optimized algorithm, which uses the (01) policy to fill the 2-slot void under this traffic condition.

Example 2. Uniform traffic ($\lambda_1 = \lambda_2 = \cdots = \lambda_S = \lambda$).

Theorem 1. If the traffic is uniform as defined above, then the greedy policy (111…1) is an optimal policy and $T_{min}(s) = 1/\lambda$ for all s.

Proof.

(a) From Eq. (3), Theorem 1 is true for s = 1.

(b) If Theorem 1 is true for s = 2, 3…□, then $\lambda_i T_{min}(\sigma + 1 - i) = \lambda\left(1/\lambda\right) = 1$ for all $i \in \{1,2, \ldots, \sigma\}$, so that, from Lemma 1 and Eq. (2):

$$T_{min}(\sigma+1) = min_{\boldsymbol{P}^{\sigma+1}} \frac{1+\sum_{i=1}^{\sigma} p_i^{\sigma+1}}{\lambda\left(p_{\sigma+1}^{\sigma+1}+\sum_{i=1}^{\sigma} p_i^{\sigma+1}\right)} = \frac{1}{\lambda} \quad (6)$$

for all policies $\boldsymbol{P}^{\sigma+1}$ with $p_{\sigma+1}^{\sigma+1} = 1$, including the greedy policy (1, 1, 1, …, 1), soTheorem 1 is true for all s.

q.e.d.

Notice that Theorem 1 is based on a "weak" optimality for the (111…1) policy, as all other policies with $p_s^s = 1$ will perform just as well under a uniform traffic. However, this weak optimality is good enough to eliminate any traffic unawareness penalty associated with the use of the greedy algorithm under uniform traffic.

Theorem 2. Let there be a void with size S, and let $\lambda_1 = \lambda_2 = \cdots = \lambda_{S-1} = \lambda$. Then, the optimal policy for the S-size void will be:

(a) the greedy policy (111...1), if $\lambda_S < \lambda$;

(b) any policy that accepts requests for all S slots ($p_S^S = 1$), including the greedy policy, if $\lambda_S = \lambda$;

(c) (000...01), if $\lambda_S > \lambda$.

Proof. From Theorem 1, we know that $\lambda_i T_{min}(S - i = \lambda 1 \lambda = 1$ for all $i \in 1,2,\ldots,S-1$. Therefore, from Eq. (2) and Lemma 1, we have:

$$T_{min}(S) = \left(\frac{1}{\lambda_S}\right) min_{\boldsymbol{P}^s}\left(\frac{1+\sum_{i=1}^{S-1} p_i^s}{1+\frac{\lambda}{\lambda_S}\sum_{i=1}^{S-1} p_i^s}\right) \quad (7)$$

If $\lambda_S < \lambda$, the function to be minimized in Eq. (7) has a denominator that increases with $\sum_{i=1}^{S-1} p_i^s$ faster than the numerator, so the minimization is achieved by maximizing $\sum_{i=1}^{S-1} p_i^s$, which is achieved by making $p_i^S = 1$ for all $i \in \{1,2, \ldots, S-1\}$, thus identifying the greedy policy (111...1) as the only optimal policy. The resulting optimal performance will be given by $T_{min}(S) = \frac{S}{[\lambda_S+(S-1)\lambda]}$.

If $\lambda_S = \lambda$, the minimization is indifferent to the values of p_i^S for all $i \in \{1,2, \ldots, S-1\}$, and $T_{min}(S) = \frac{1}{\lambda}$, as shown in Theorem 1.

Finally, if $\lambda_S > \lambda$, the function to be minimized in Eq. (7) has a numerator that increases with $\sum_{i=1}^{S-1} p_i^s$

faster than the denominator, so the minimization is achieved by minimizing $\sum_{i=1}^{s-1} p_i^s$, which is achieved by making $p_i^S = 0$ for all $i \in \{1,2,\dots,S-1\}$, thus identifying (000...01) as the only optimal policy. The resulting optimal performance will be given by $T_{min}(S) = \frac{1}{\lambda_S}$.

q.e.d.

Example 3. Linearly increasing traffic: $\lambda_i = i\lambda,\ i = 1,2,3,\dots$

Theorem 3. If $\lambda_i = i\lambda$ for all i, then (000…01) is the optimal policy with $T_{min}(s) = 1/(s\lambda)$ for all s.

Proof. Eqs. (3) and (4) show that Theorem 2 is true for S = 1 and 2 respectively. If it is also true for S= 3, 4, …, $\sigma - 1$, then:

$$T_{min}(\sigma) = \min_{p_1^\sigma, p_2^\sigma, \dots, p_{\sigma-1}^\sigma} \left[\frac{1 + \frac{p_1^\sigma}{\sigma-1} + \frac{2p_2^\sigma}{\sigma-2} + \cdots + \frac{(\sigma-2)p_{\sigma-2}^\sigma}{2} + (\sigma-1)p_{\sigma-1}^\sigma}{1 + \frac{p_1^\sigma}{\sigma} + \frac{2p_2^\sigma}{\sigma} + \frac{3p_3^\sigma}{\sigma} + \cdots + \frac{(\sigma-1)p_{\sigma-1}^\sigma}{\sigma}} \right] \frac{1}{\sigma\lambda} \quad (8)$$

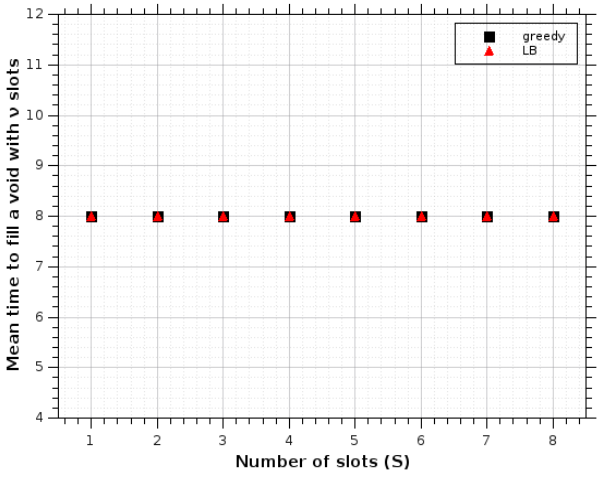
In the expression between brackets, notice that the coefficient that multiplies p_i^σ in the numerator is larger than in the denominator forall$i \in \{1,2,\dots,\sigma - 1$. Therefore, the minimization is achieved by making $p_i^\sigma = 0$ for all $i \in \{1,2,\dots,\sigma-1\}$, yielding $T_{min}(\sigma) = 1/(\sigma\lambda)$ and proving Theorem 2.

q.e.d.

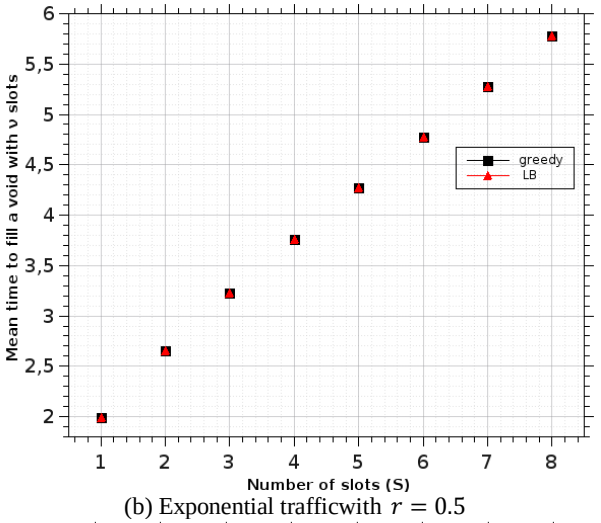
In the case of linearly increasing traffic, severe greediness penalties may be incurred by the use of the FF algorithm: G(2) = 4/3 = 1.333…, G(3) = 11/6 = 1.8333…, G(4) = 107/45 = 2,377…,G(5) = 529/180 = 2,93888… , and so on, suggesting that G(s) runs away to infinity as s grows. Next section shows other three examples.

3. Numerical Results

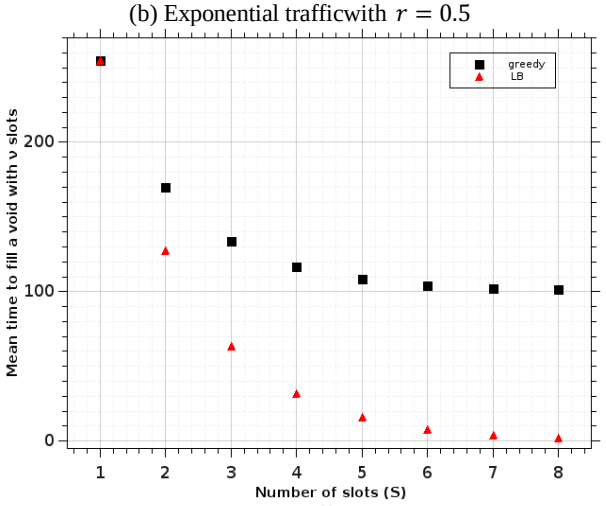
In this section, we compare the performance of the greedy spectrum assignment algorithm with the optimized traffic-aware algorithm (i.e., the one that minimizes the mean spectrum fulfillment time), hereby denoted as LB (lower-bound). Figs. 1a-1c compare the mean time to activate all slots in voids of size $s = 1,2,\dots,8$ underuniform and exponential traffic conditions. Under exponential traffic, the ratiobetween



(a) Uniform traffic



(b) Exponential trafficwith $r = 0.5$



(c) Exponential traffic with $r = 2$

Fig. 1 Mean time to activate all slots in voids of sizes $= 1,2,\dots,8$ under different traffic conditions.

consecutive request rates is given by a constant r (i.e., $\lambda_1 = \lambda$; $\lambda_2 = r\lambda$; ...; $\lambda_S = r^{S-1}\lambda$). We have considered a descending (r=0.5) and ascending (r=2) traffic profile. In addition, all results assume normalized arrival rates ($\sum_{i=1}^{s} \lambda_i = 1$) for fair comparison. As it can be seen, for uniform and descending exponential traffic profile with r = 0.5, the greedy algorithm is optimal, since no other heuristics can provide better performance. However, for an ascending exponential traffic condition, as the void size increases, the traffic unawareness feature of the greedy algorithm imposes a severe penalty to the average fulfillment time. For instance, when $s = 8$, the average time to spectrum exhaustion of the best possible assignment is less than 2% of the one provided by the greedy assignment, which corresponds to a "traffic greediness price" of around $G(8) = 50.84$. For higher void sizes, the traffic greediness price is even higher, which can be easily inferred from the results, which stress the importance of considering a traffic-aware strategy for acceptance or rejection of path requests if spectrum resources are aimed to be most efficiently used in the network.

4. Conclusions

We have shown that the enhanced flexibility of elastic optical networks may be impaired by adverse traffic profiles if the resource assignment algorithm is unaware of them. Some traffic profiles may cause severe penalties associated with the traffic unawareness of the greedy algorithm. On the other hand, the greedy algorithm may be used with no penalty at all if more friendly traffic profiles, such as the uniform traffic and others, are used. A constructive method was presented to build an optimal, traffic-aware spectrum assignment algorithm for any given profile, and a few theorems were proved for specific profile types and neighboring conditions.

Our results were derived for a very simple topology (the single link) in a very simple networking environment (incremental traffic). Further investigation into the traffic unawareness penalties is going on, and extension of our results to dynamic networking environments and more complex topologies is planned.

Acknowledgments

This work was supported by CAPES, CNPq and FACEPE.

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Journal of Communication and Computer
Volume 10, Number 11, November 2013
David Publishing Company
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Tel: 1-323-984-7526, 323-410-1082; Fax: 1-323-984-7374, 323-908-0457
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ISSN 1548-7709